



Thinking about processing steps for generation of combined/compatible Landsat 8 & Sentinel-2 products

Roy, D.P., Kovalskyy, V., Zhang, H.K., Yan, L., Kumar. S.

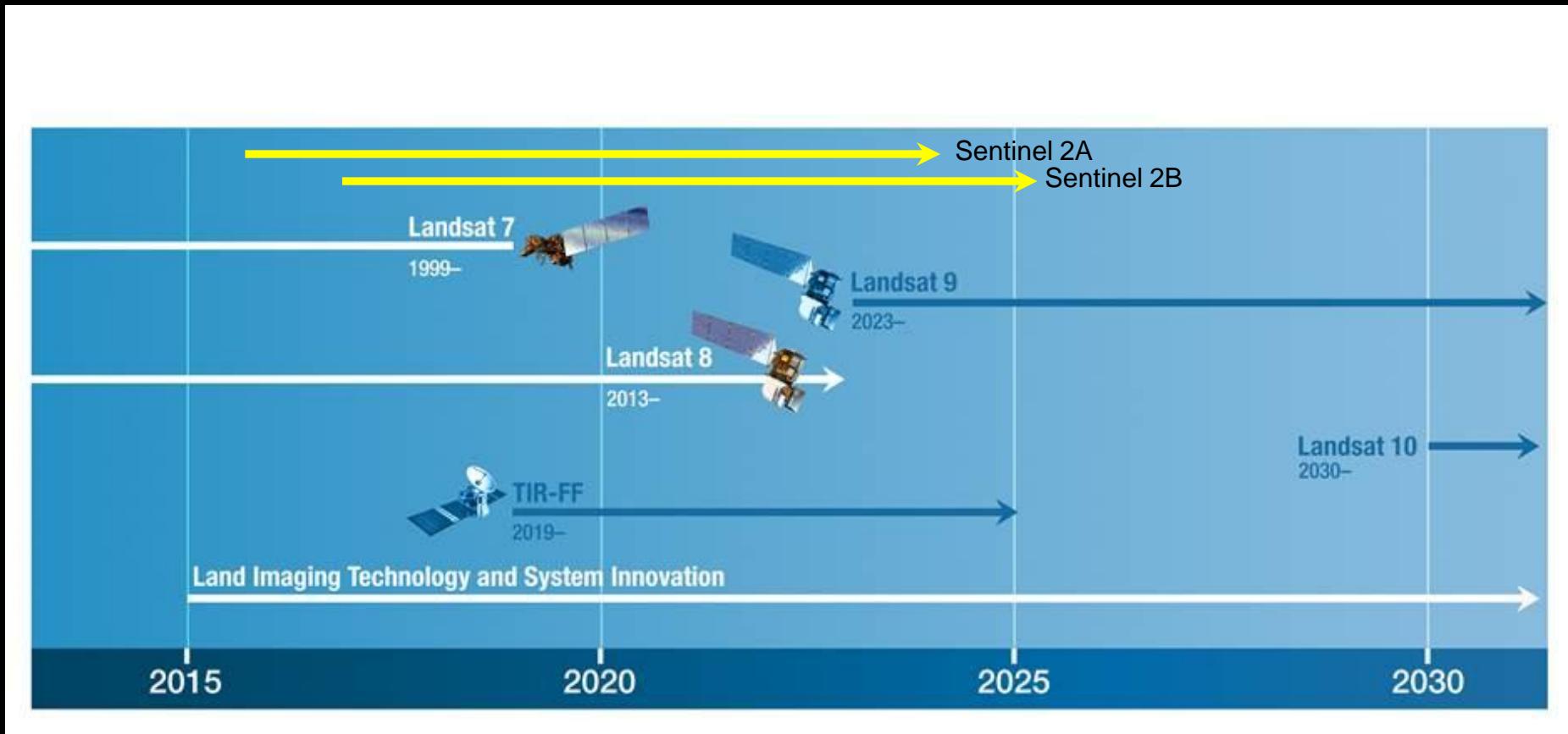
Geospatial Science Center of Excellence
South Dakota State University

Summer 2015 Landsat Science Team Meeting
USGS Earth Resources Observation and Science (EROS) Center

July 6-9 2015



NASA USGS commitment for Landsat 9 & 10 !



ESA commitment for Sentinel 2A & 2B !

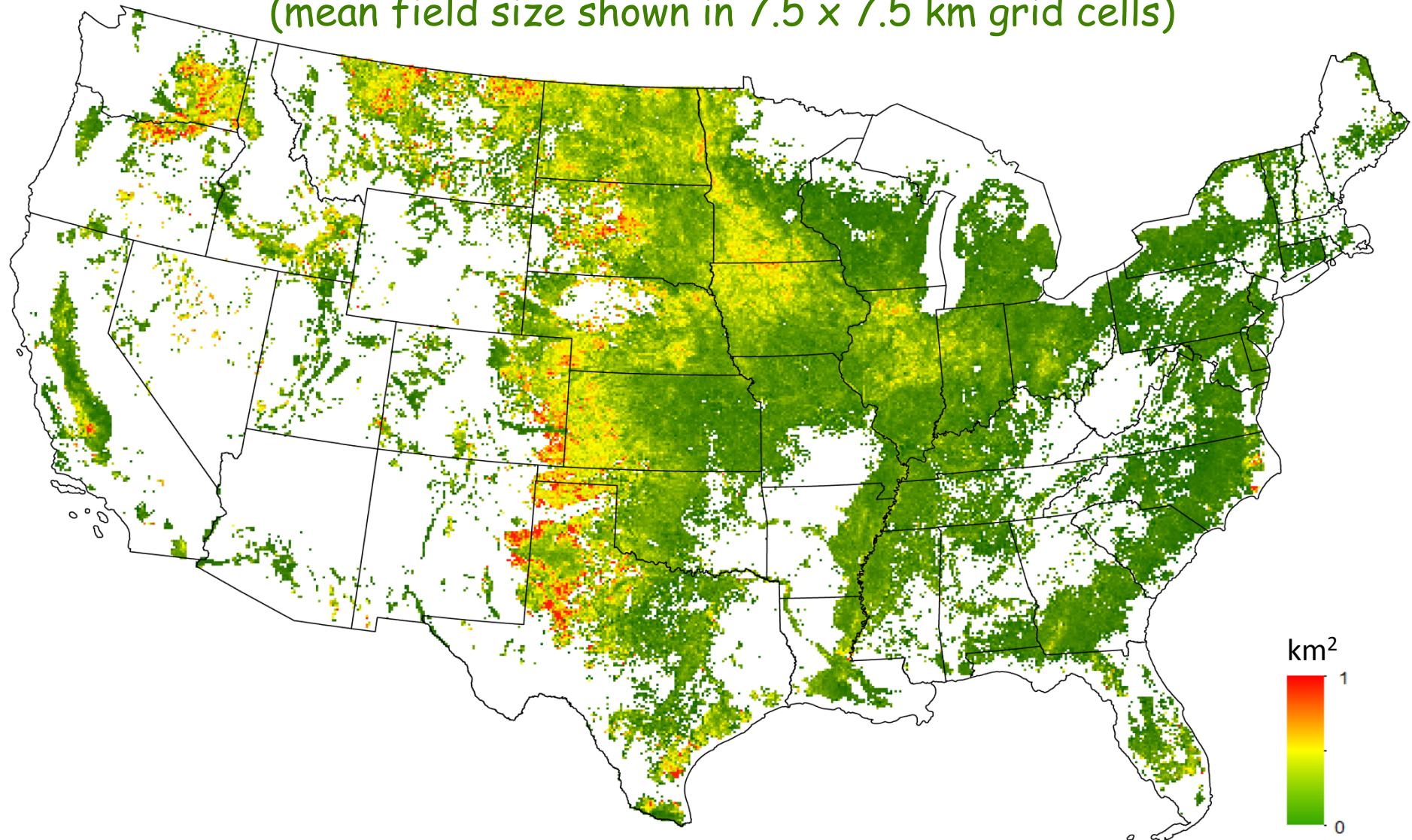
Combined/Compatible Sentinel-2 & Landsat 8

Prerequisite for

- combined use of different optical λ (thermal L8) sensor data
- developing algorithms
- prototyping products
- to advance the “virtual constellation paradigm for mid-resolution land imaging”

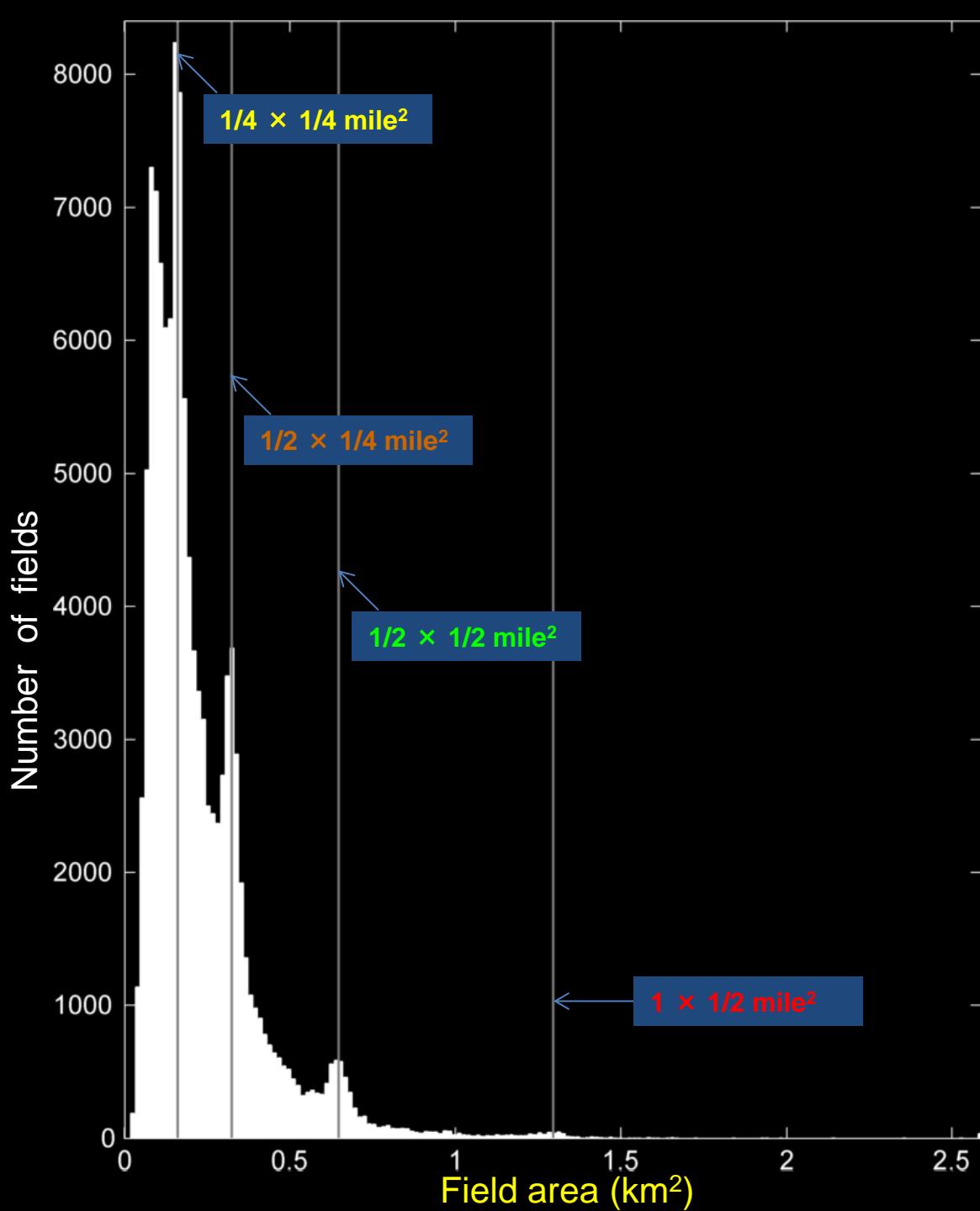
2010 CONUS crop field size map

(mean field size shown in 7.5×7.5 km grid cells)



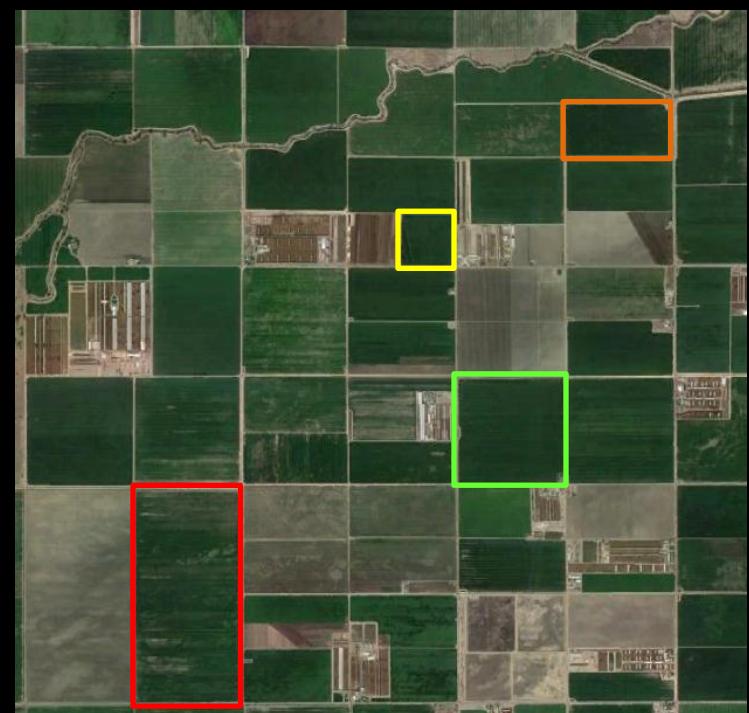
derived from all 13,666 WELD processed [Landsat 5](#) and [7](#) scenes
available in the U.S. Landsat archive for 12 months

(Yan & Roy 2015)

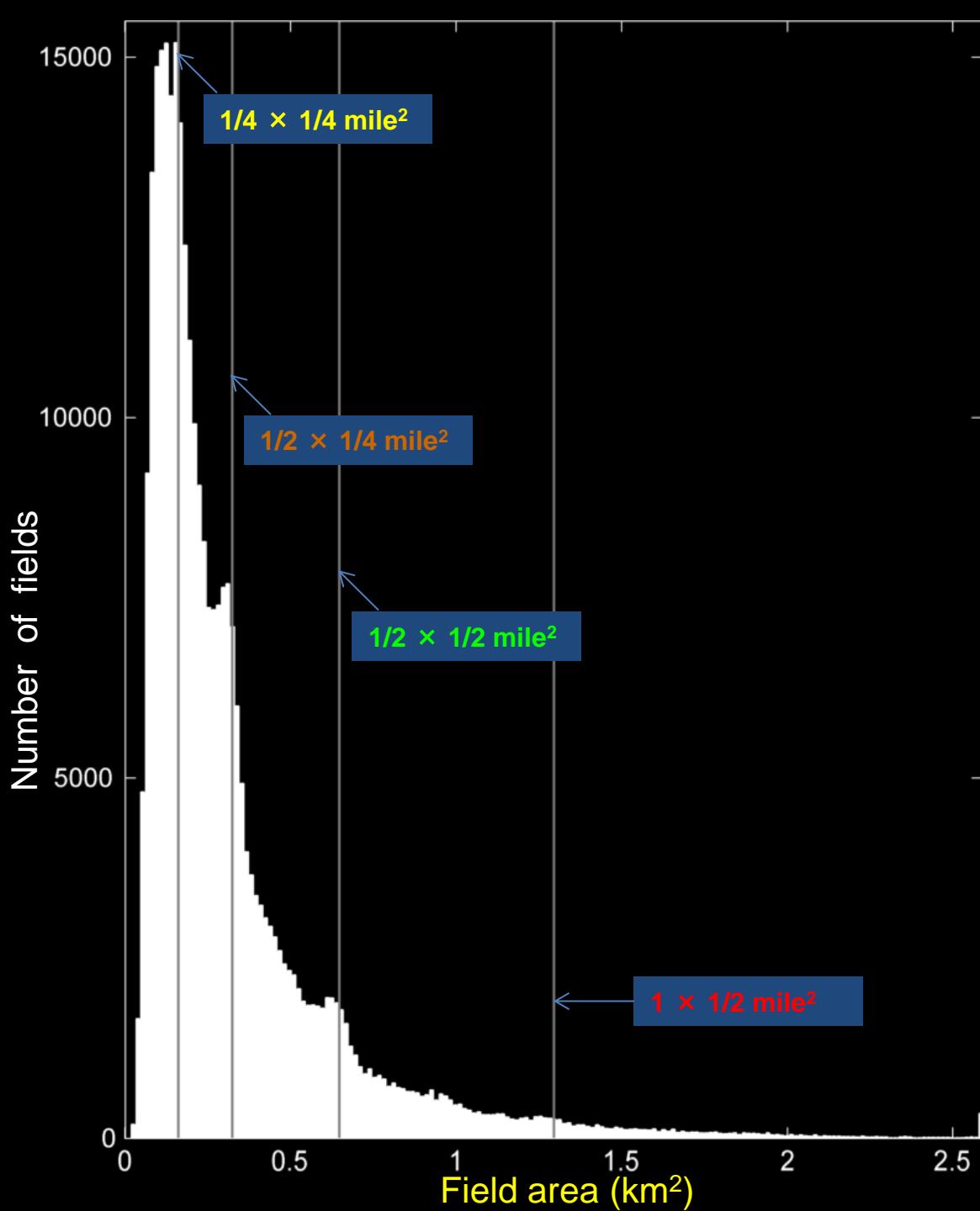


California 2010
WELD derived
crop field size histogram

116,888 fields extracted



Google-Earth image. $\sim 5.5 \times 5 \text{ km}$
subset in California near Corcoran.

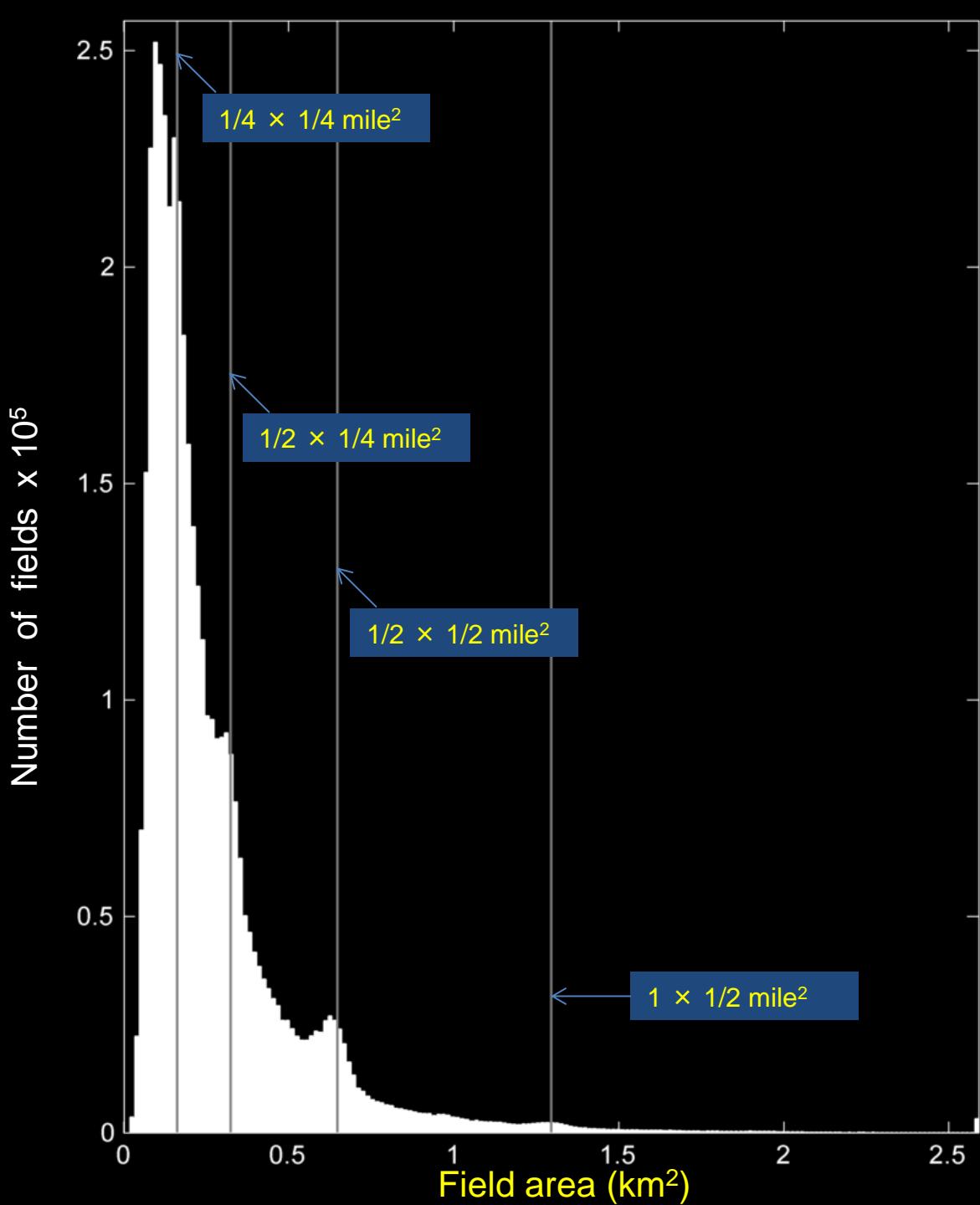


Iowa 2010
WELD derived
crop field size histogram

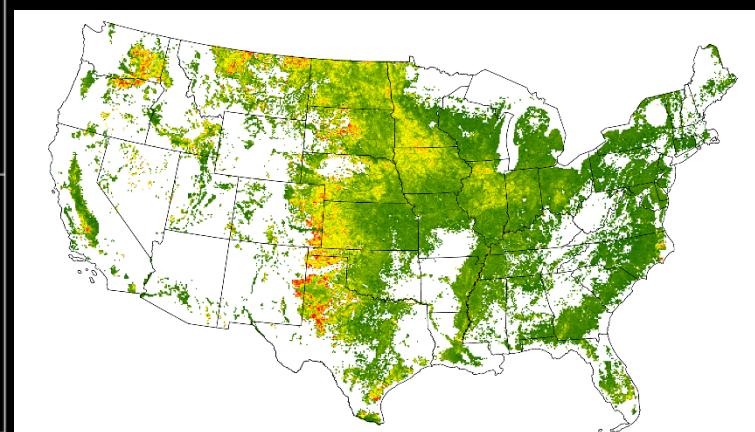
308,917 fields extracted



Google-Earth image. ~5.5 x 5 km
subset in Iowa near Eagle Grove.



CONUS 2010
WELD derived
crop field size histogram
4,182,777 fields extracted



NASA NNH14ZDA001N Land Cover/Land Use Change (LCLUC14-2): Multi-Source Land Imaging Science

Multisource Imaging of Seasonal Dynamics in Land Surface Phenology	Friedl/BU
Integrating Landsat 7, 8 and Sentinel 2 Data in Improving Crop Type Identification and Area Estimation	Hansen/UMD
Towards Near Daily Monitoring of Inundated Areas Over North America Through Multi-Source Fusion of Optical and Radar Data	Lang / UMD
Prototyping a Landsat-8/Sentinel-2 Global Burned Area Product	Roy / SDSU
Operational Algorithms and Products for Near Real Time Maps of Rice Extent and Rice Crop Growth Stage Using Multi-Source Remote Sensing	Salas / Applied Geosystems
Multi-Source Imaging of Infrastructure and Urban Growth Using Landsat, Sentinel and SRTM	Small / Columbia U
Multi-Source Imaging of Time-Serial Tree and Water Cover at Continental to Global Scales	Townshend / UMD



(Gutman, Masek)



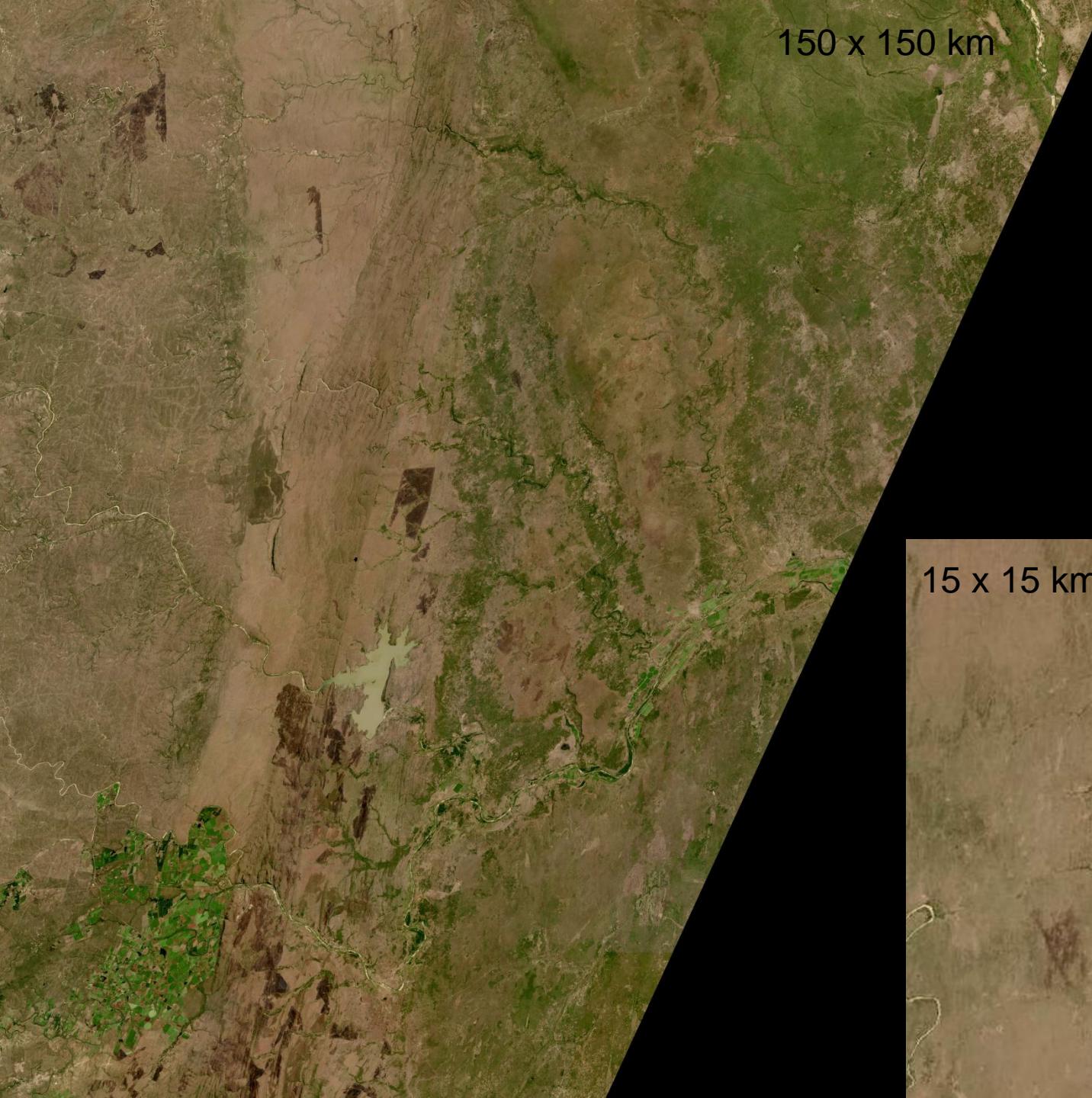
NASA NNH14ZDA001N Land Cover/Land Use Change (LCLUC14-2): Multi-Source Land Imaging Science

Multisource Imaging of Seasonal Dynamics in Land Surface Phenology	Friedl/BU
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(Gutman, Masek)





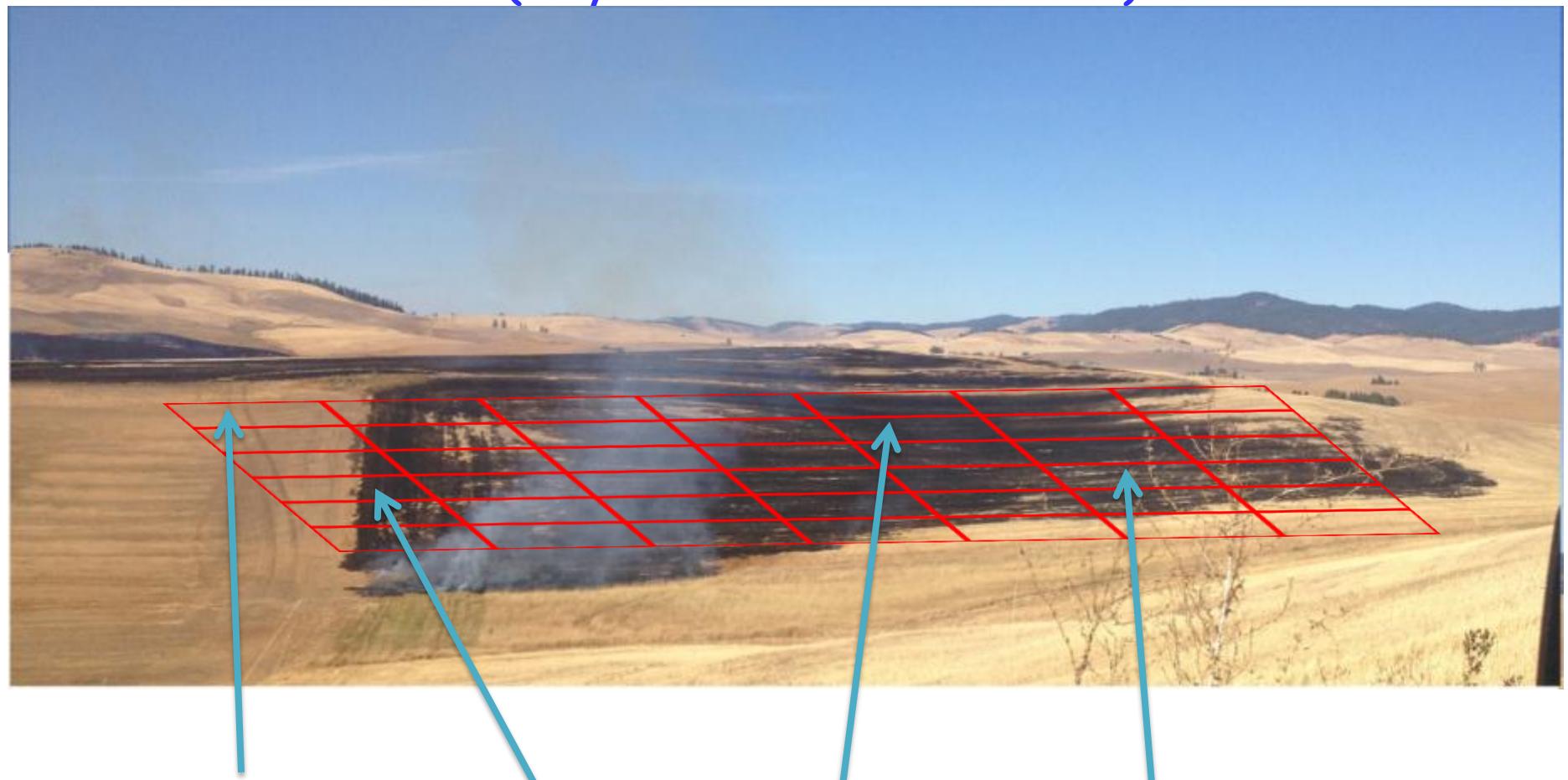
Prototyping a Landsat-8 Sentinel-2 Global Burned Area Product

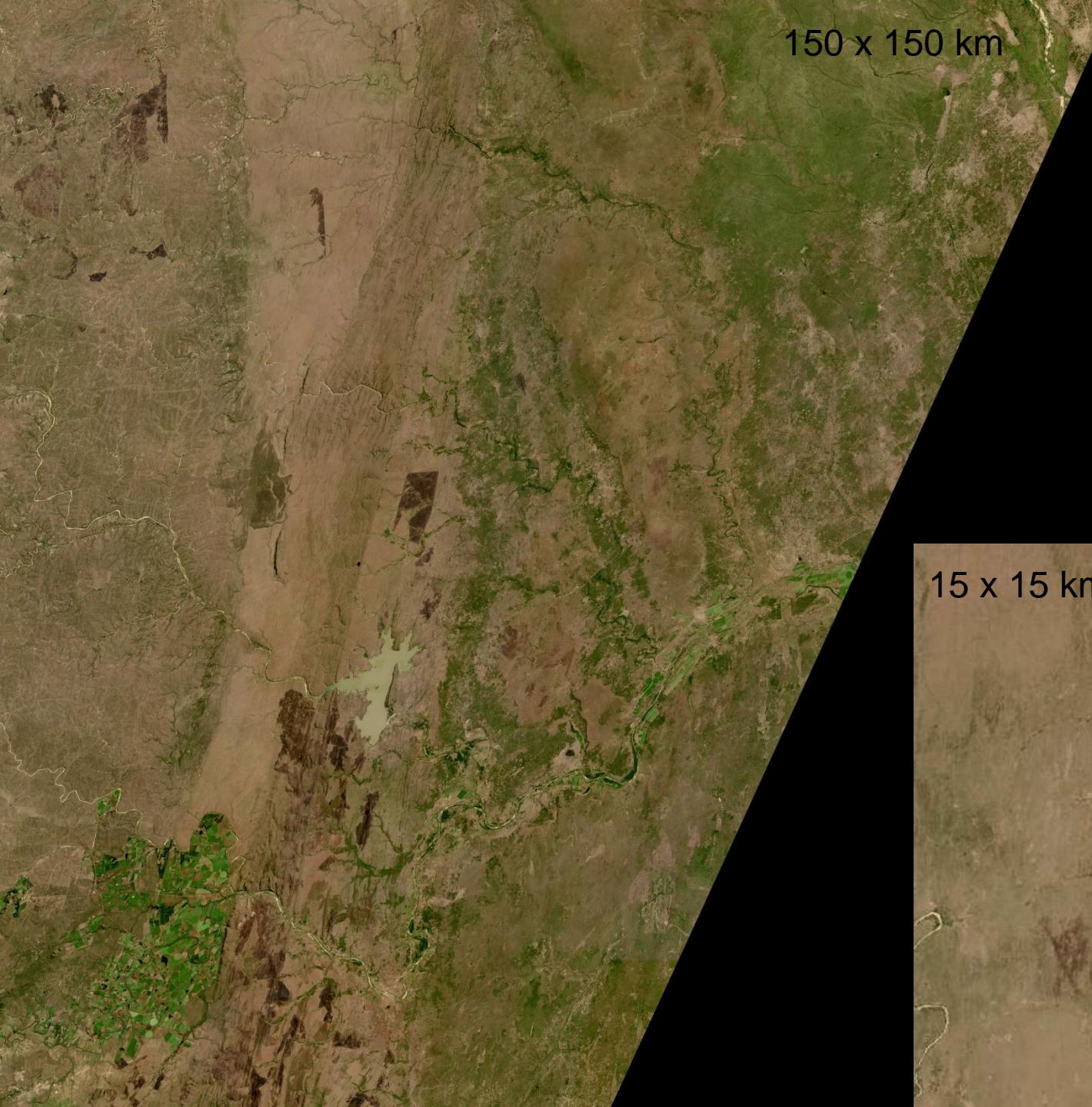
WELD Landsat 8,
30m true color,
Week 23 2014
South Africa/Moz.

15 x 15 km



A pixel is a mix of burned and unburned stuff:
model as a sub-pixel fraction (f) burned and the
combustion completeness (cc) within the burn
(Roy and Landmann 2005)



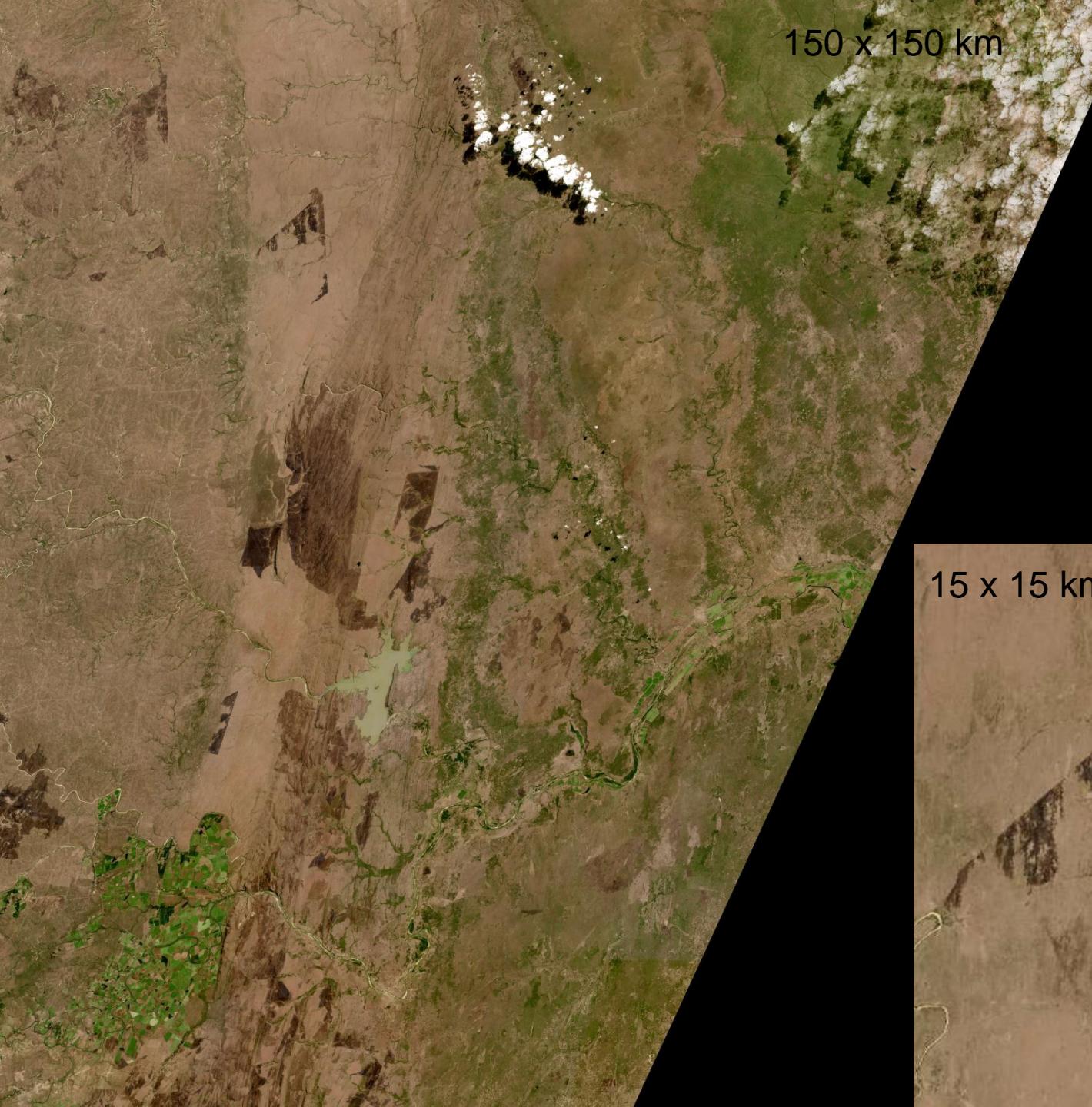
A large satellite map showing a 150x150 km area of southern Africa, specifically focusing on South Africa and Mozambique. The map displays a mix of brown, green, and dark brown terrain, with numerous small agricultural fields and river networks visible.

150 x 150 km

WELD Landsat 8,
30m true color,
Week 23 2014
South Africa/Moz.

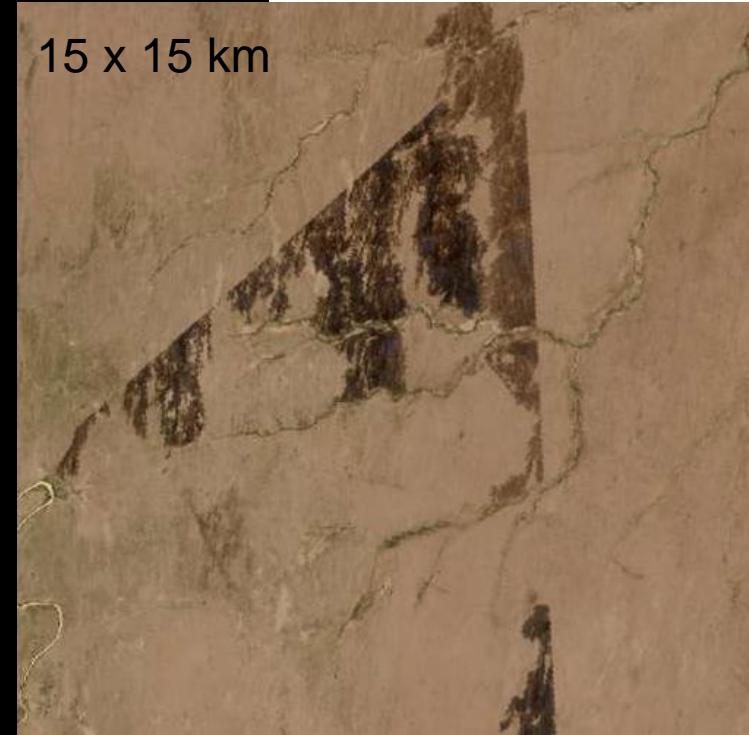
A zoomed-in satellite view of a 15x15 km area within the main map, located in the central southern African region. It shows a close-up of the brown, arid land with some darker, possibly agricultural or forested areas, and a network of thin, winding white lines representing roads or water courses.

15 x 15 km

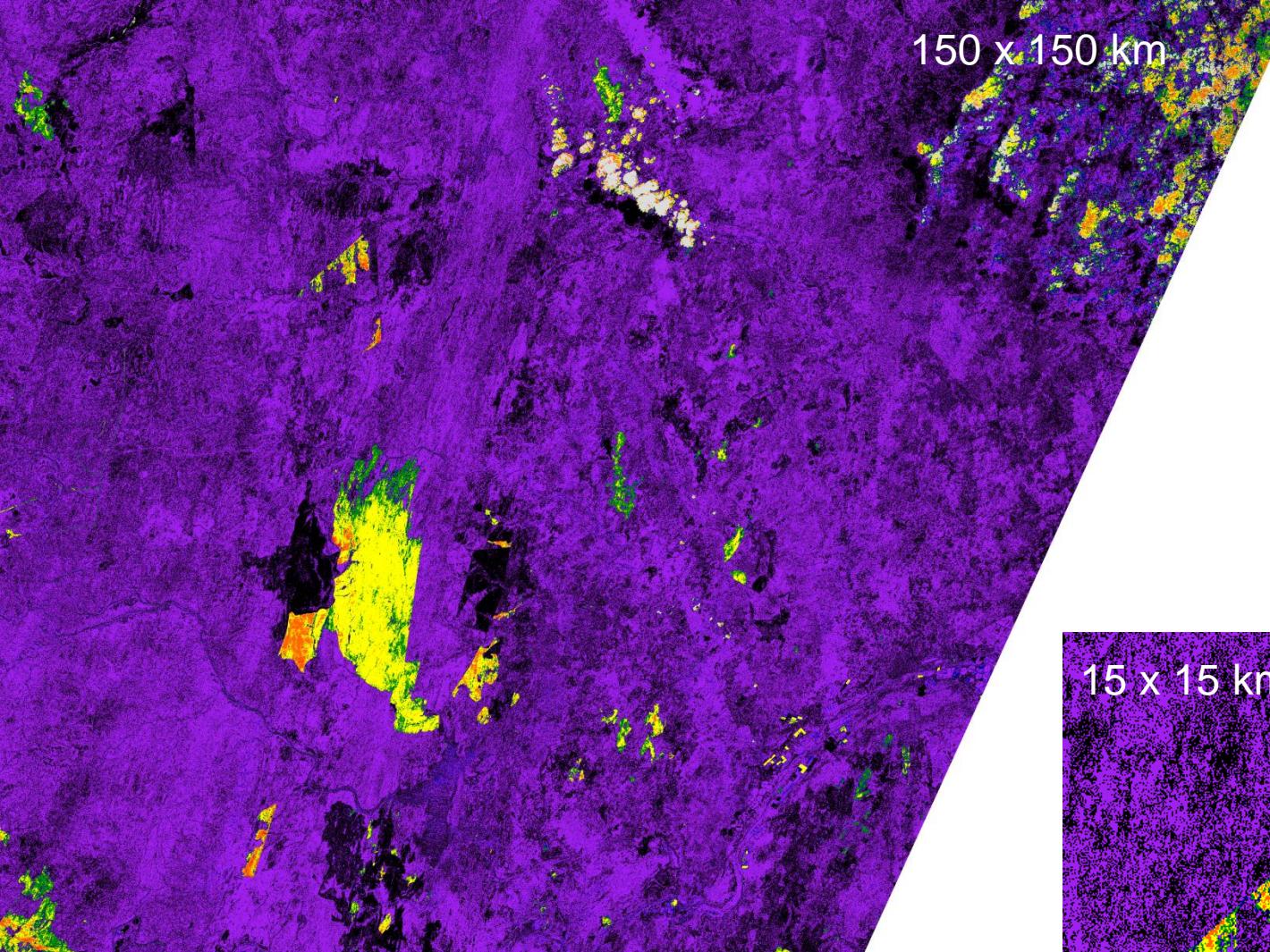
A large satellite map showing a coastal region with brown land and green vegetation. A prominent white cloud band is visible near the coast. The map is divided into two sections by a diagonal black line.

150 x 150 km

WELD Landsat 8,
30m true color,
Week 25 2014
South Africa/Moz.

A close-up satellite view of a brown, textured area, likely a coastal or arid region. The image is framed by a black border.

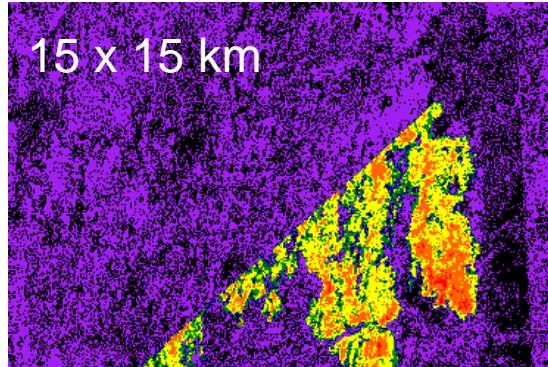
15 x 15 km



150 x 150 km

f . cc retrieval,
and burned area
mapping
proof of concept

Landsat 8,
Week 23 to 25 2014
South Africa/Moz.

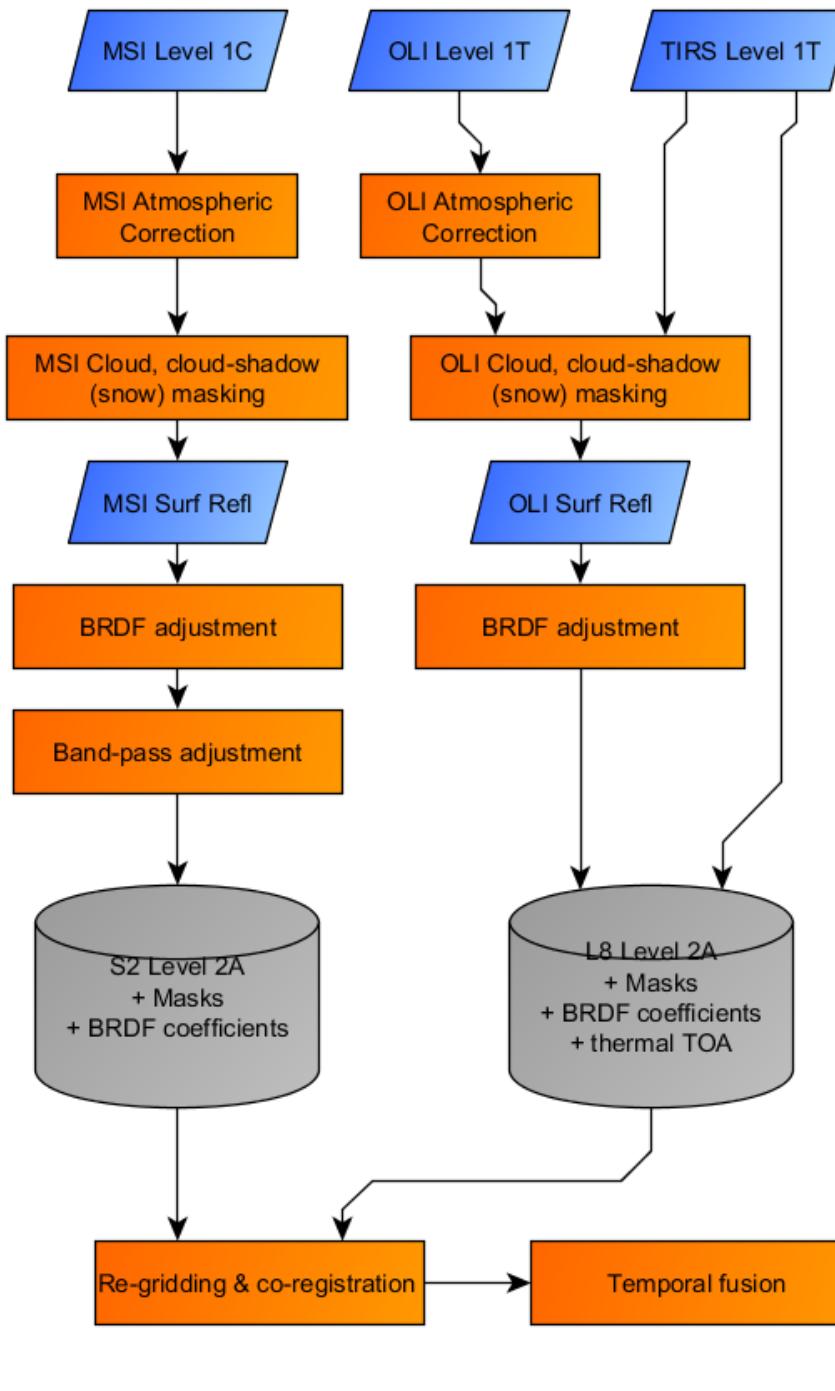


15 x 15 km

Research plan (2015-2018):

- integrate Sentinel 2 with Landsat 8 under WELD
- develop automated f.cc & burned area 30m mapping algorithm
- apply for Africa & select global samples
- validate with Planet Labs imagery (burned area) & Canopy Biomass Lidar (f.cc)

Processing for Landsat/S2 Harmonization



- Algorithms

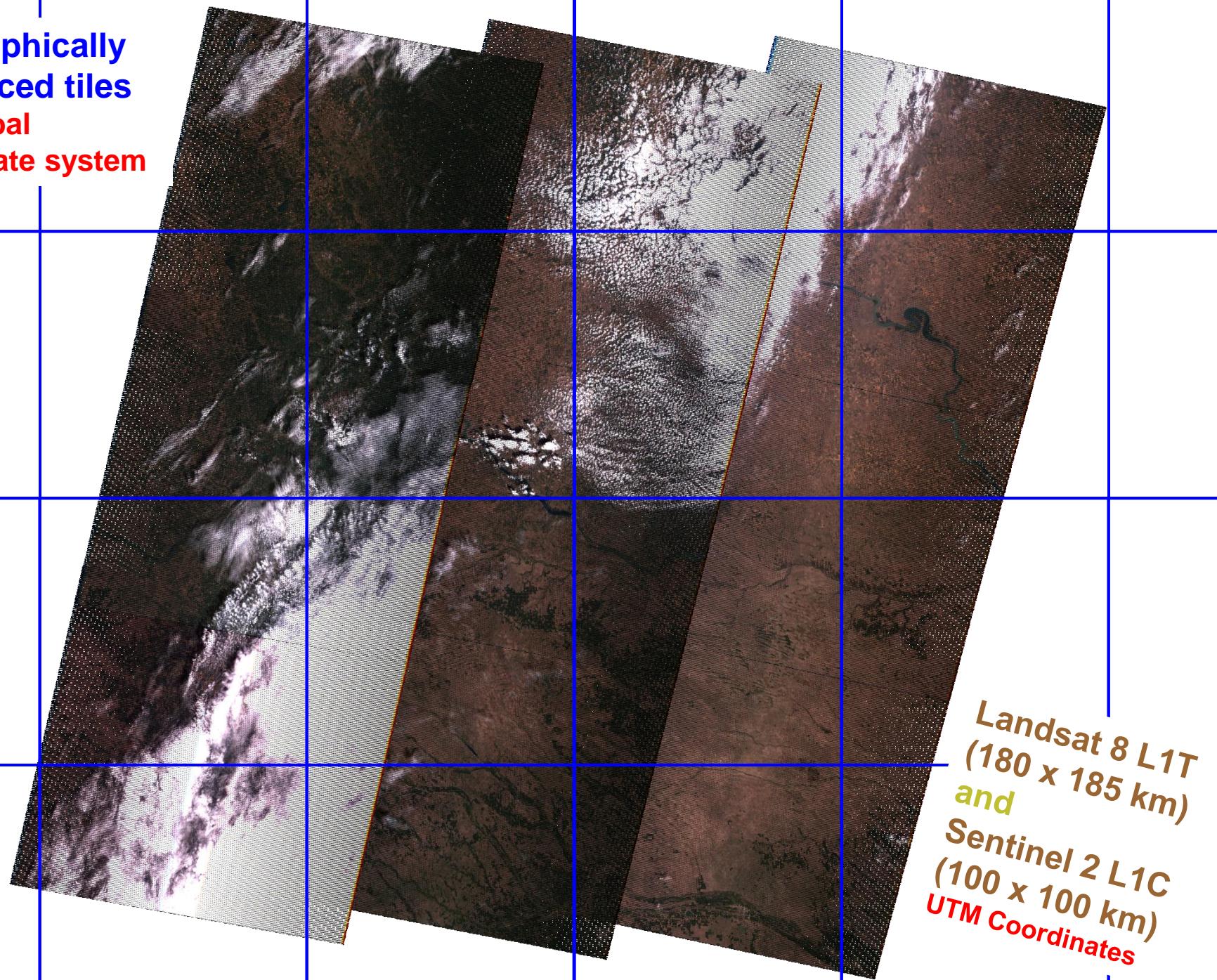
- Atmospheric correction
- Cloud/shadow masking
- BRDF adjustment to nadir view
- Band-pass adjustment to OLI
- Regridding
- Temporal Compositing
 - 30m WELD sinusoidal gridding
 - 6-day composites
 - TIR from best Landsat-8
 - Red-edge from best S2a
 - VSWIR from either



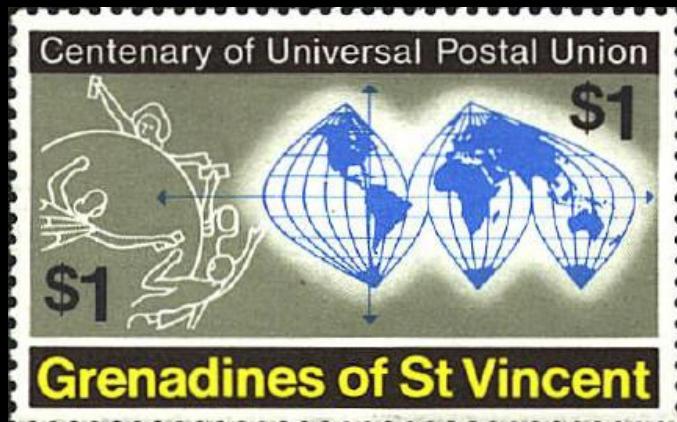
(Jeff Masek, yesterday)

Regridding/Projection approach for Sentinel-2 & Landsat 8

Geographically
referenced tiles
in a global
coordinate system



Project Landsat 8 L1T & Sentinel 2 L1C UTM data to the same Global Projection - which ?



Interrupted projections too complex for users



Uninterrupted projections easier



Also, polar uninterrupted projection needed for cryospheric research ?

Project Landsat 8 L1T & Sentinel 2 1LC UTM data to the same Global Projection - which ?

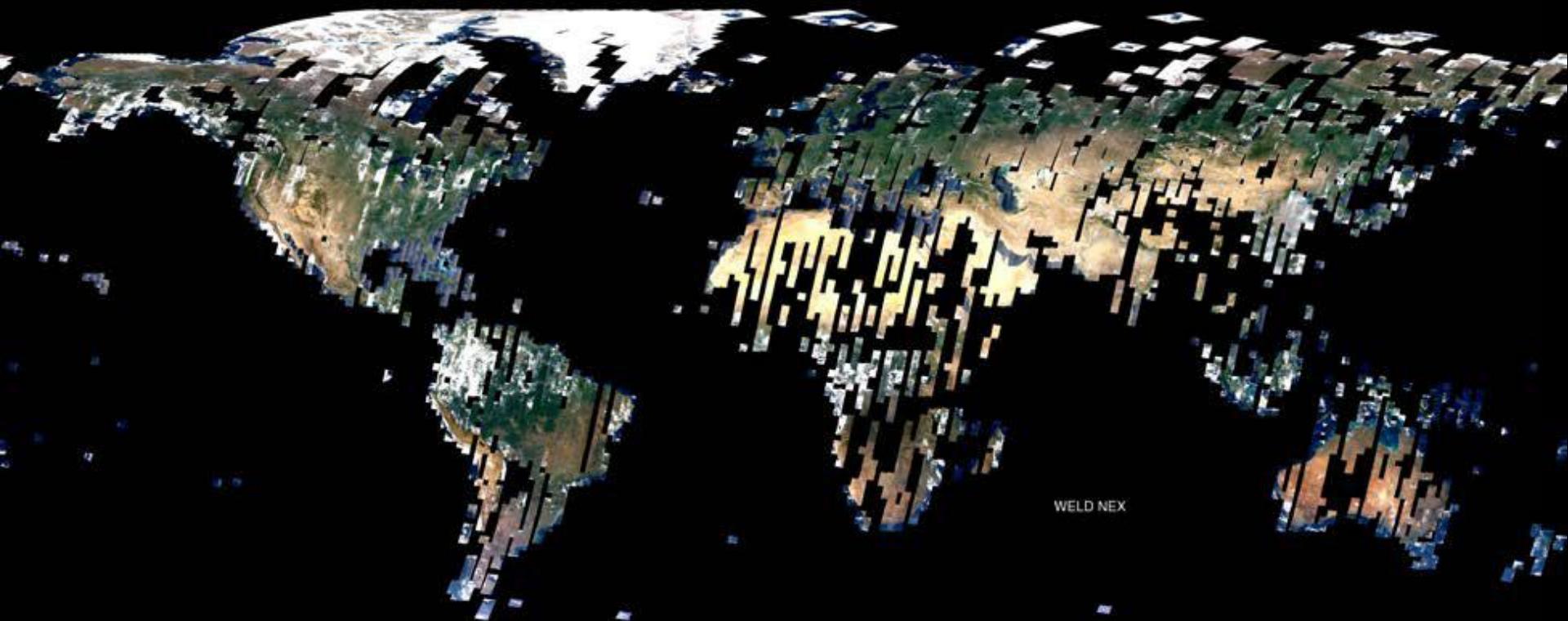
Should be

- equal area & uninterrupted
 - supported by publically available transformation software (GCTP, GDAL)
 - have closed-form inverse mapping (otherwise computing inverse expensive)
 - familiar to users
-
- Mercator Projection
 - developed 1569 for nautical navigation
 - used by Google Maps
 - But, not equal area
 - Winkel Tripel Projection
 - minimizes distortion in area, direction and distance
 - used by the National Geographic Society
 - But, closed-form inverse mapping does not exist
 - Sinusoidal Equal Area Projection
 - satisfies criteria, developed for global change community, MODIS land products!



Early prototype Global monthly WELD product

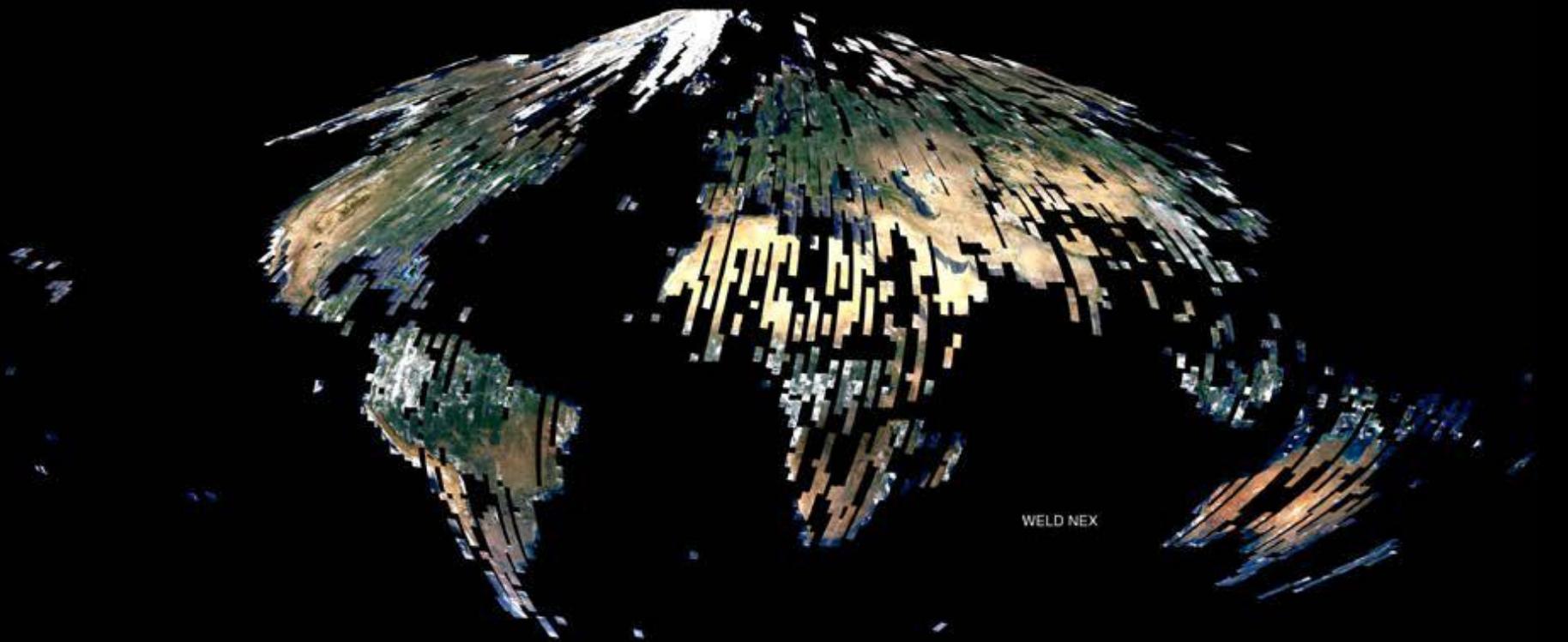
Geographic Lat./Long. projection



Each 1.35km true color browse pixel
generated from 45 x 45 30m Landsat 7 ETM+ pixels

Early prototype Global monthly WELD product

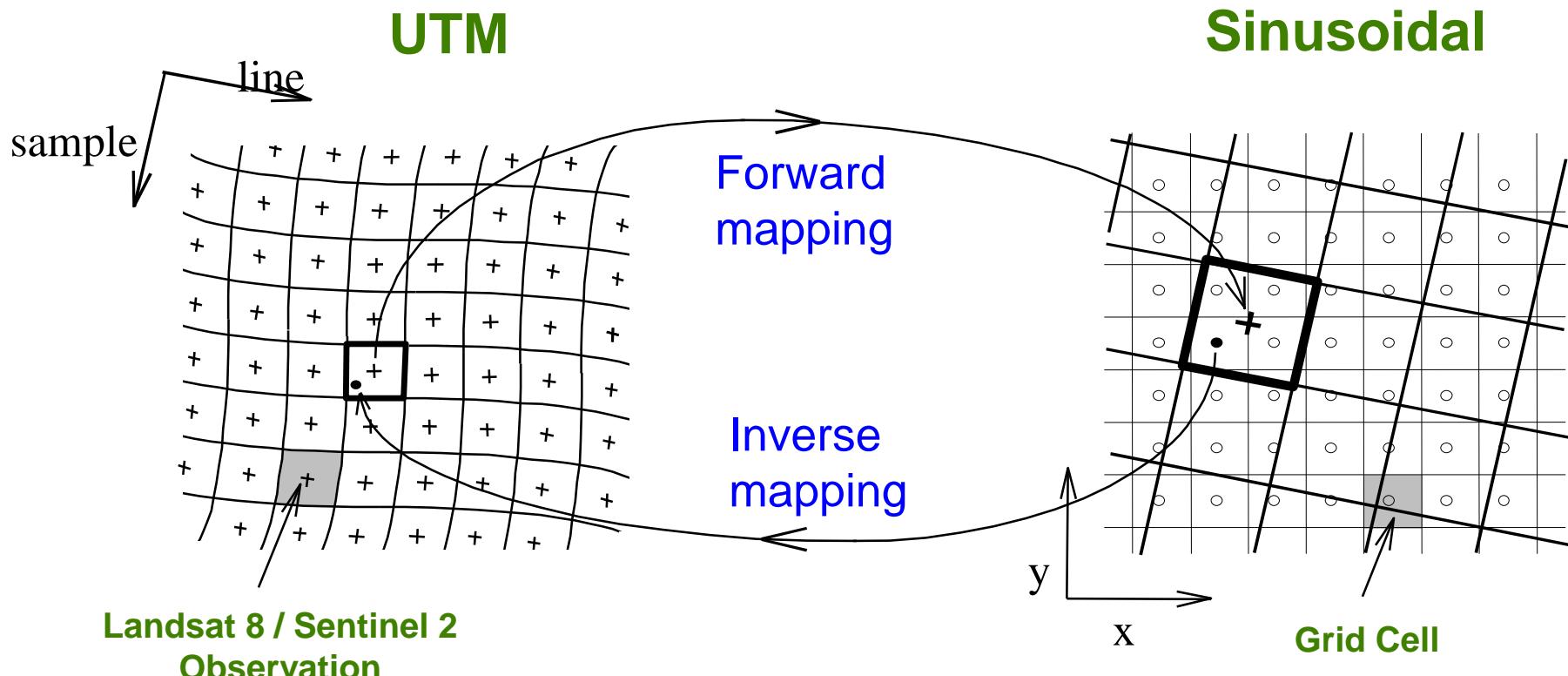
Equal area sinusoidal projection

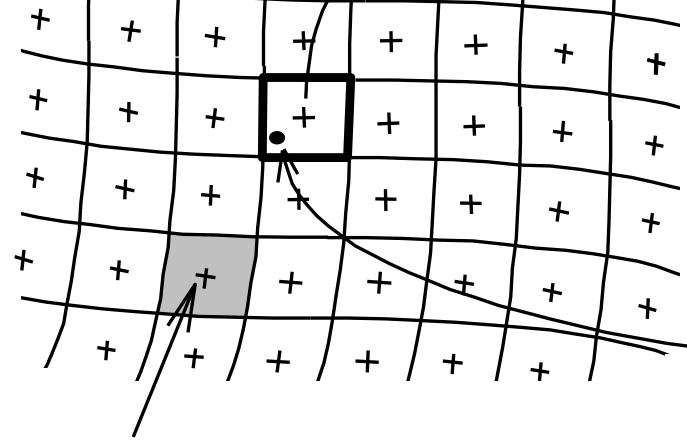


Each 1.35km true color browse pixel
generated from 45 x 45 30m Landsat 7 ETM+ pixels

Reprojection UTM <-> Sinusoidal which mapping approach ?

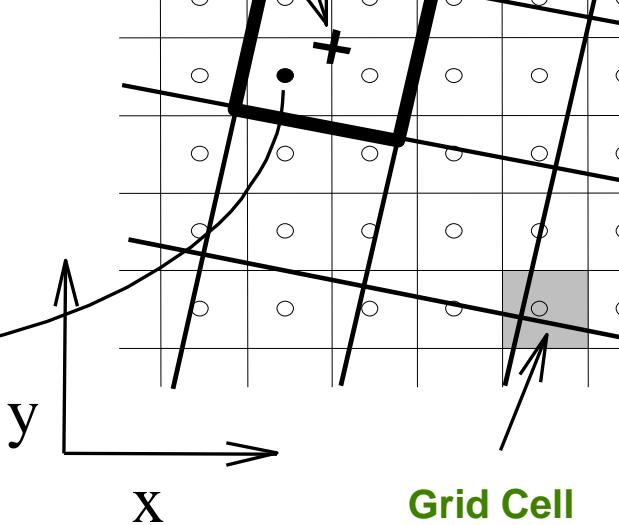
Use inverse mapping as computationally least expensive, each global pixel location only addressed once, no gaps in output.





Resampler ?

Inverse
Mapping



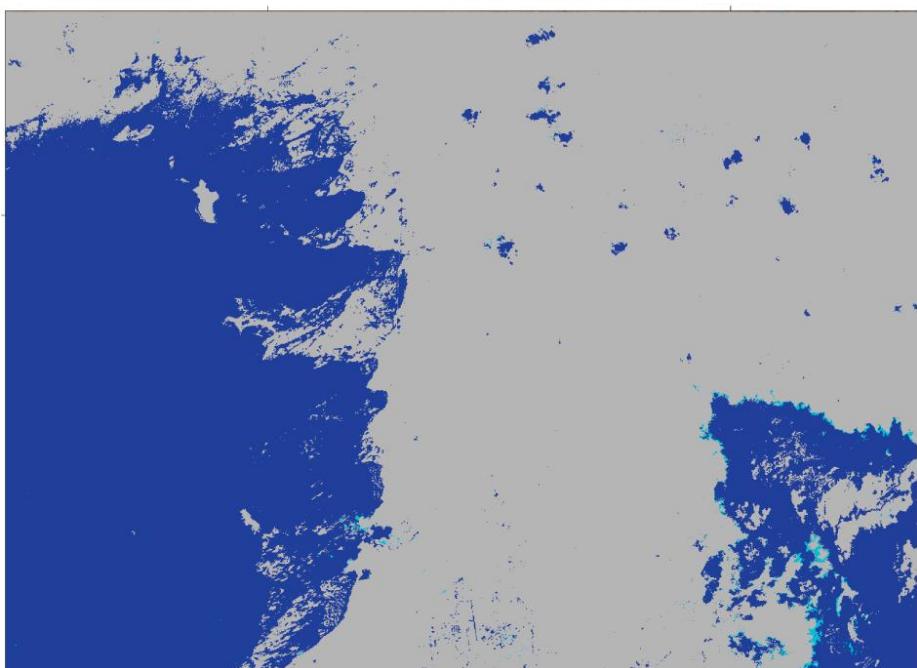
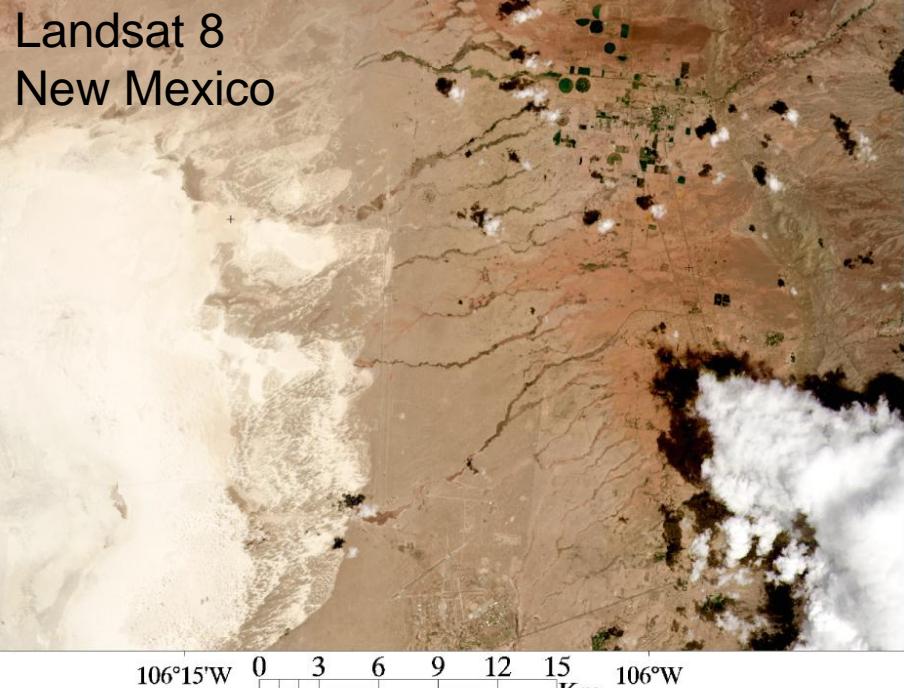
Landsat 8 / Sentinel 2
Observation

Grid Cell

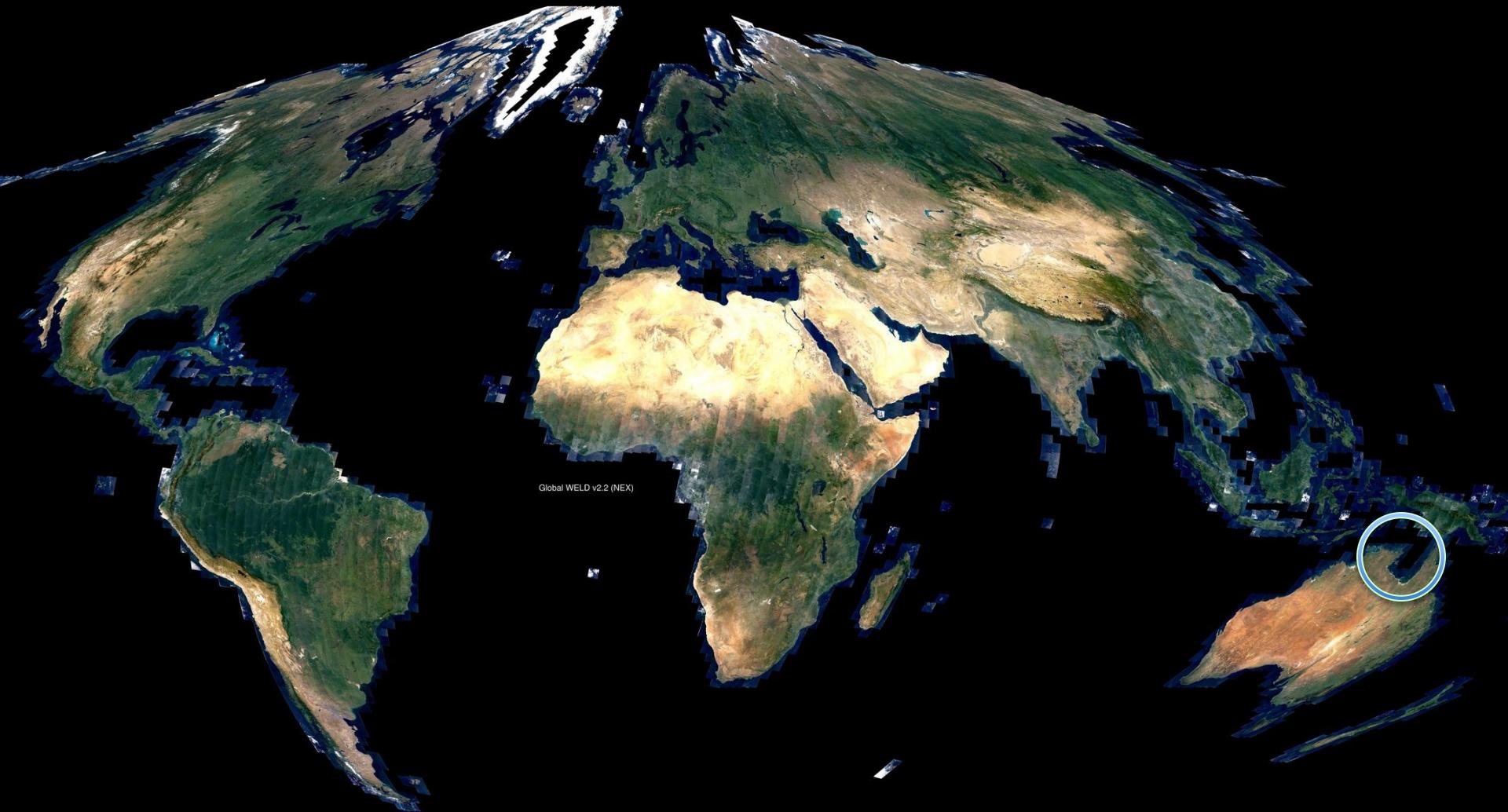
Use nearest neighbor resampling to preserve categorical & ordinal per-pixel QA information after reprojection

Kovalskyy, V. and Roy, D.P., 2015
A one year Landsat 8 conterminous United States study of cirrus and non-cirrus clouds,
Remote Sensing, 7, 564-578

high confidence clouds
medium confidence clouds
low confidence clouds



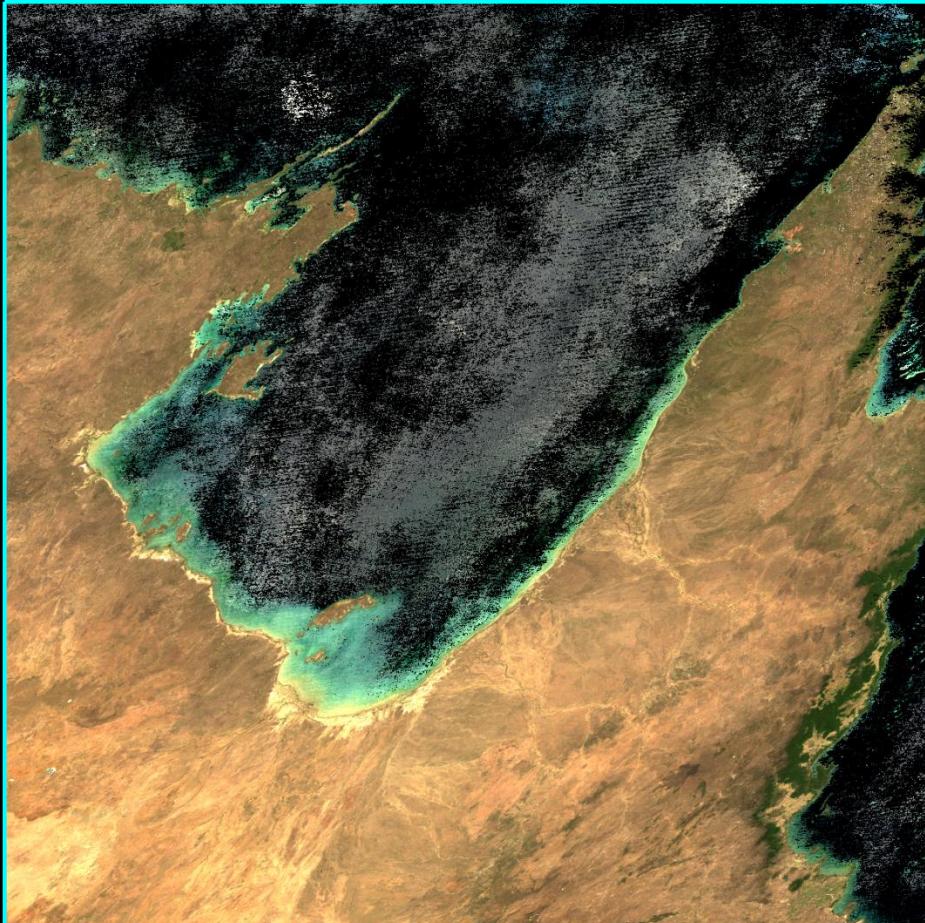
Tiling scheme ?



Global WELD NEX Annual 2010 30m product
124,433 L1T scenes (45,711 Landsat 5 & 78,722 Landsat 7)

MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

MODIS Land Tile scheme ($10 \times 10^\circ$ at Equator, 1200 × 1200 1km pixels)

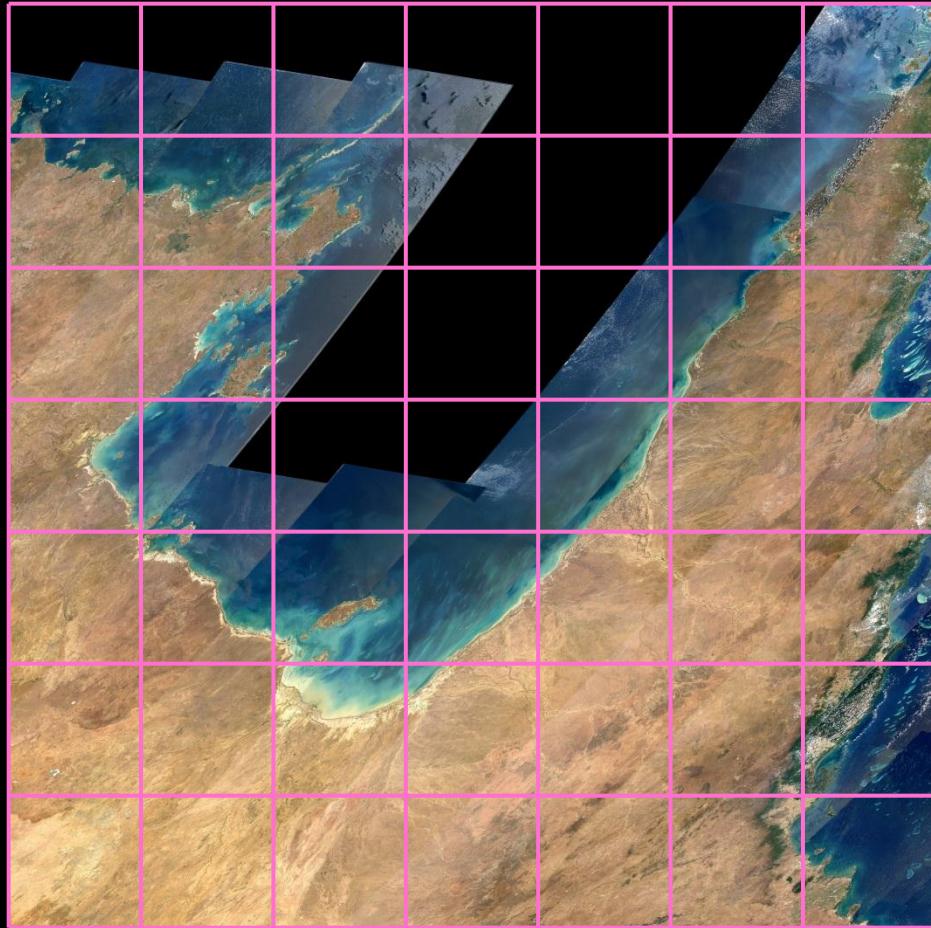


- MODIS Land tile h31v10
- MODIS nadir view BRDF-adjusted (NBAR) 500m true color reflectance
- Terra and Aqua daily surface reflectance for October 2009

Gulf of Carpentaria, Australia

Landsat WELD tiling

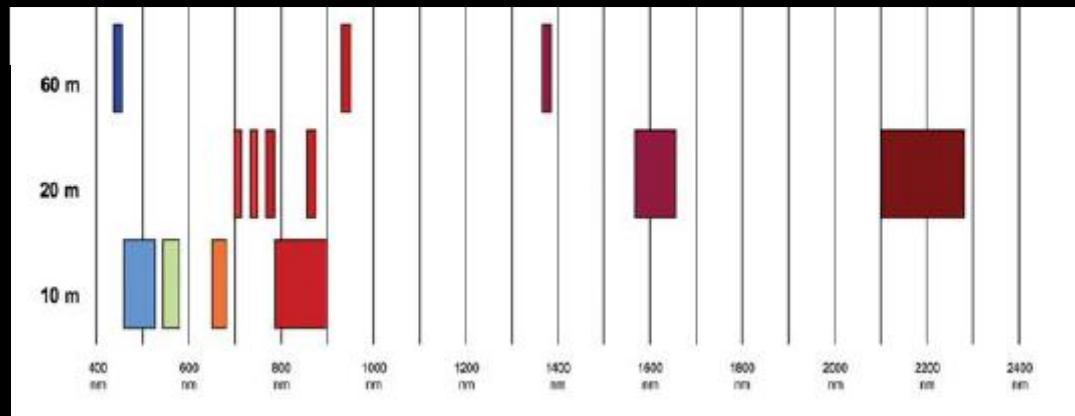
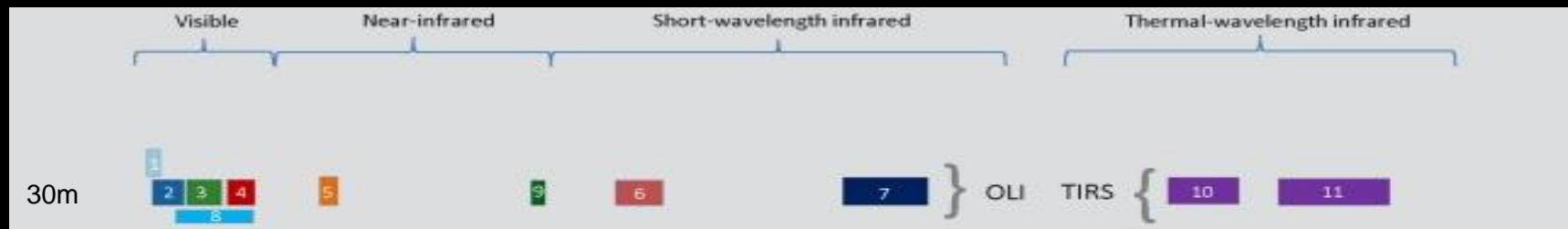
(49 158 × 158 km tiles nested in each MODIS tile)



- Landsat 7 ETM+ & Landsat 5 TOA true color 30m reflectance composite
- Global WELD Version 2.2 monthly product
- October 2009
- 7 x 7 WELD tiles nested within a single MODIS tile
- each 5295 x 5295 30m pixels (158 x 158 km)

L57.Globe.month09.2009.hh31vv10.h1v7.doy248to273.v2.2.hdf

Temporal Compositing approach for Sentinel-2 & Landsat 8



Landsat 8 (L8) and
Sentinel 2 (S2)
different
spectral & spatial
resolutions

Best pixel selection compositing over reporting period

- L8 and S2 bands separately (some users want this)
- L8-S2 surface NBAR fused (others users want this)

WELD compositing applied to Top of Atmosphere (TOA) reflectance because Landsat atmospheric correction is imperfect

Derived from

- 122 10x10km ETM+ subsets atmospherically corrected using 6SV and AERONET atmospheric characterization
- at 31 AERONET sites across U.S.

Landsat 7 Band	Mean normalized residual
1 (blue)	11.8%
2 (green)	5.7%
3 (red)	5.9%
4 (NIR)	4.8%
5 (MIR)	3.6%
7 (MIR)	5.2%
NDVI	6.3%

Version 1.5 WELD compositing algorithm

Cloud QA & Max. NDVI & Max. BT heritage

Priority	Criteria	Selection	
1	IF only one none-fill	non-fill	
2	IF only one unsaturated	unsaturated	
3	IF both unsaturated	Maximum (brightness temperature)	
4	IF only one none-cloudy	none-cloudy	
5	IF one cloudy and one uncertain cloud	select uncertain cloud if it has greater brightness temperature or greater NDVI, else select cloudy	
6	IF one non-cloudy and one uncertain cloud	select non-cloud if it has greater brightness temperature or greater NDVI, else select uncertain cloud	
7	IF either below NDVI 0.09	select the one with greatest brightness temperature	"unvegetated"
8	ELSE	Maximum (NDVI)	vegetated

Roy, D.P., Ju, J., Kline, K., Scaramuzza, P.L., Kovalskyy, V., Hansen, M.C., Loveland, T.R., Vermote, E.F., Zhang, C., 2010, Web-enabled Landsat Data (WELD): Landsat ETM+ Composited Mosaics of the Conterminous United States, *Remote Sensing of Environment*, 114: 35-49.

Landsat 7 (L1T) scene projected into the WELD Albers grid



Landsat 7 (L1T) scene projected into the WELD Albers grid



WELD Version 1.5 monthly Composite



true color
TOA
reflectance

Florida

500 x 400
30m pixels

WELD Version 1.5 monthly Composite



March

true color
TOA
reflectance

Florida

500 x 400
30m pixels

Shadow & cloud edge issues over vegetation !

Landsat 7 (L1T) scene projected into the WELD Albers grid



Day 124

true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

Landsat 7 (L1T) scene projected into the
WELD Albers grid



Day 140

true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite



true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite



May
true color
TOA
reflectance

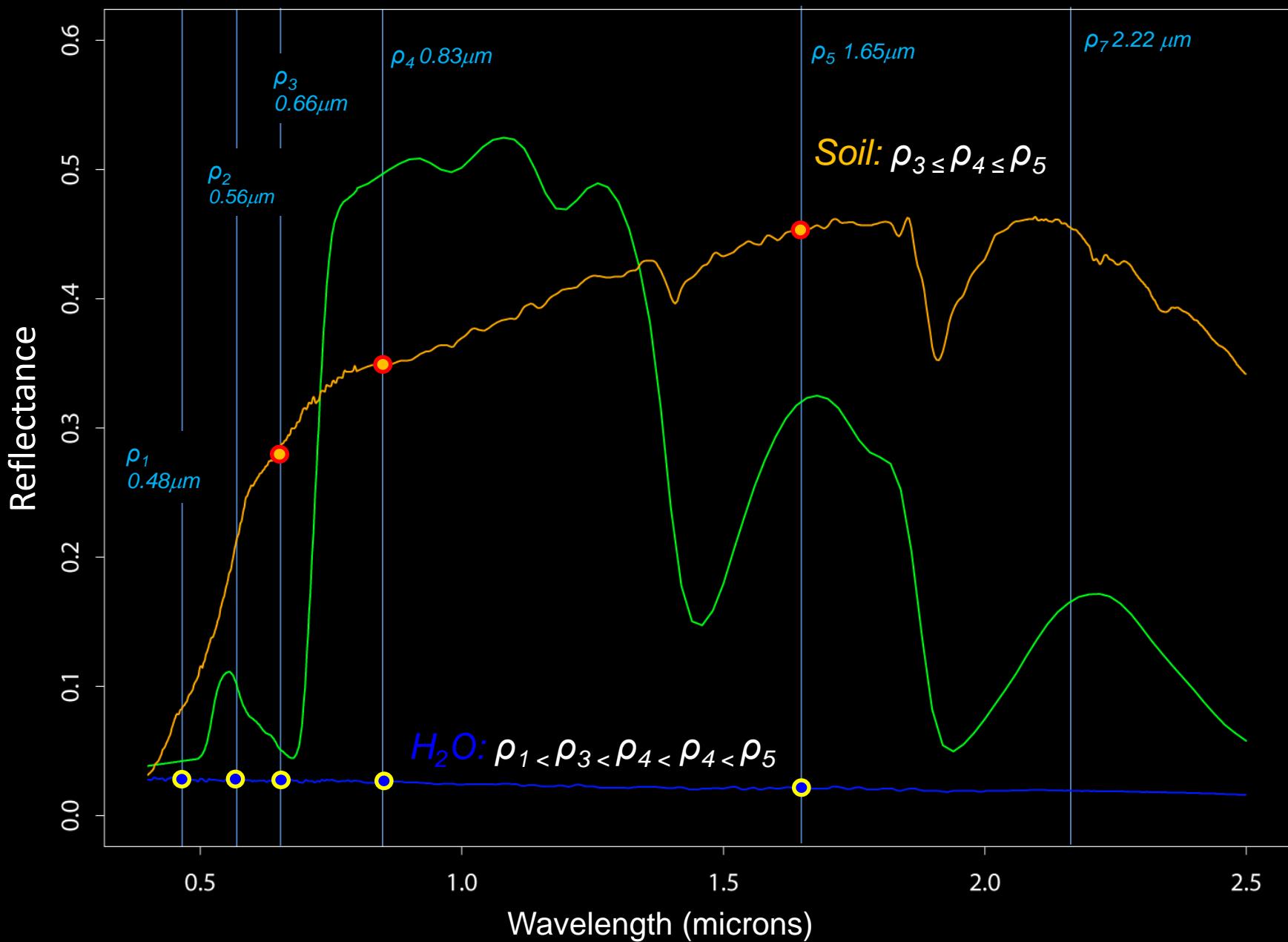
South
Dakota

500 x 400
30m pixels

Shadow & atmospheric contamination issues over soil !

Version 2.2 compositing algorithm

Use threshold free Soil & Water Tests



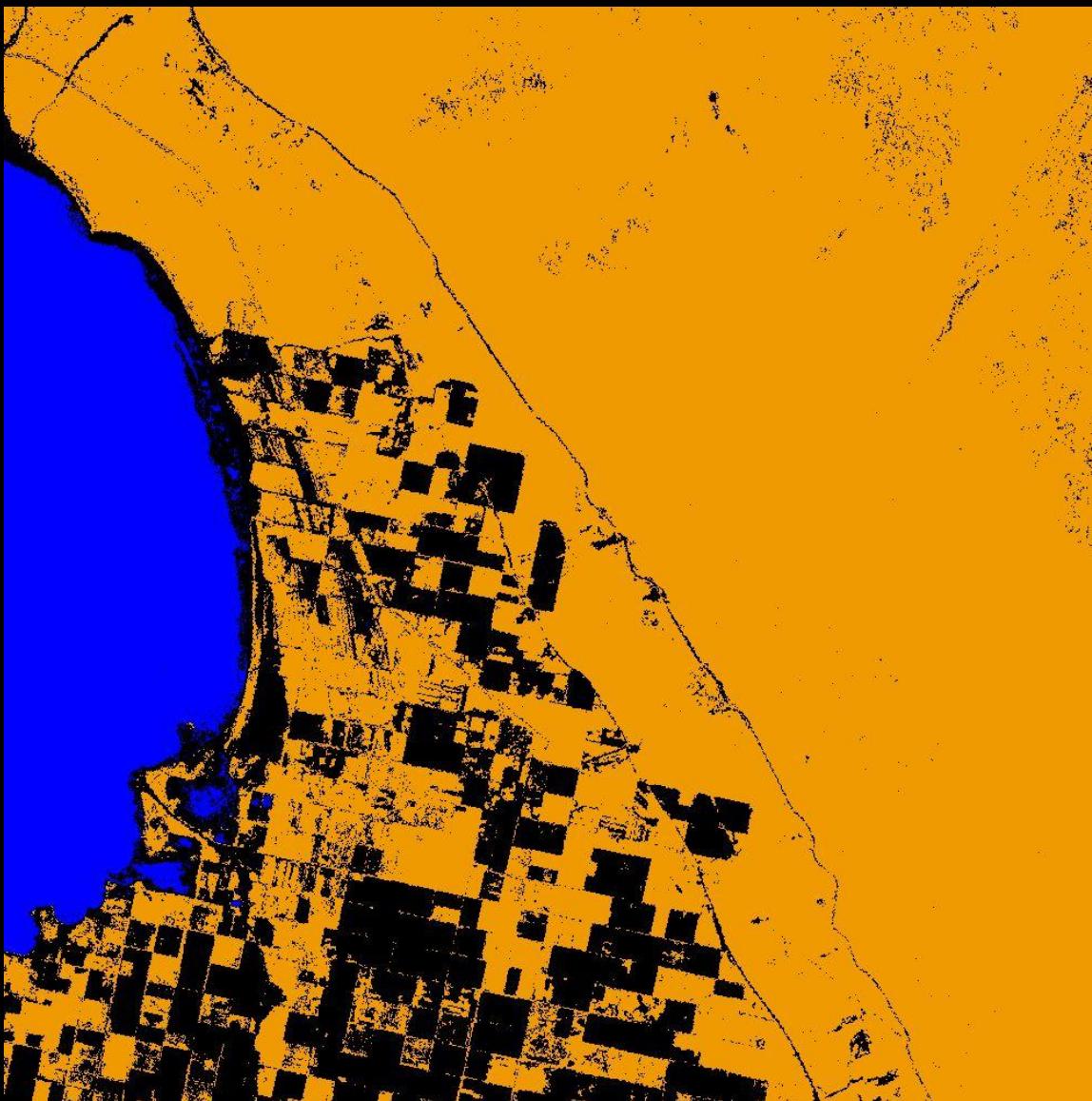
April
2008
true color
TOA
reflectance

California

500 x 400
30m pixels



Example soil and water test results



April
2008
true color
TOA
reflectance

California

500 x 400
30m pixels

WELD Version 1.5 monthly Composite



May
2008
true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 2.2 monthly Composite



May
2008
true color
TOA
reflectance

South
Dakota

500 x 400
30m pixels

WELD Version 1.5 monthly Composite



March
2008
true color
TOA
reflectance

Florida

500 x 400
30m pixels

WELD Version 2.2 monthly Composite



March
2008
true color
TOA
reflectance

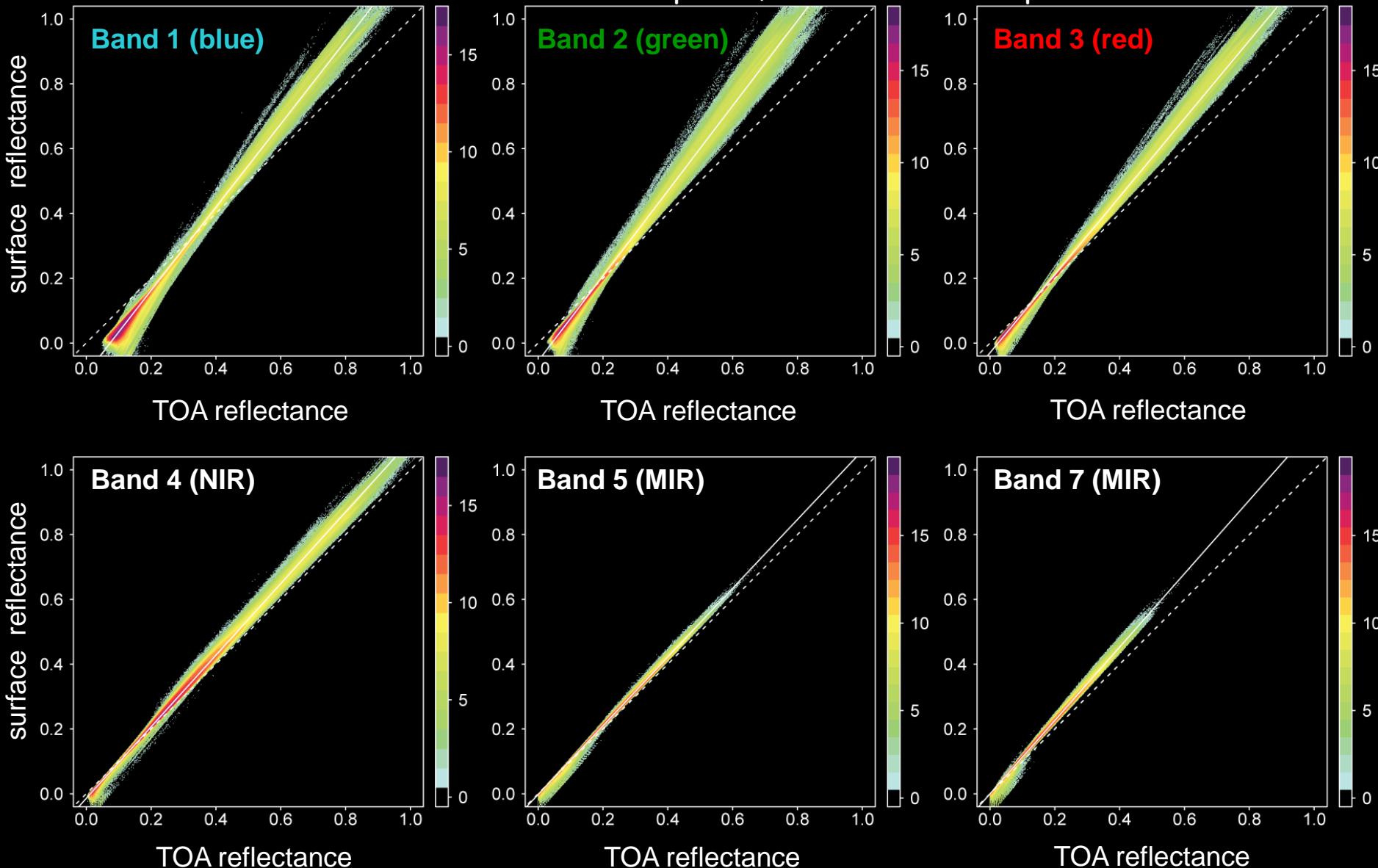
Florida

500 x 400
30m pixels

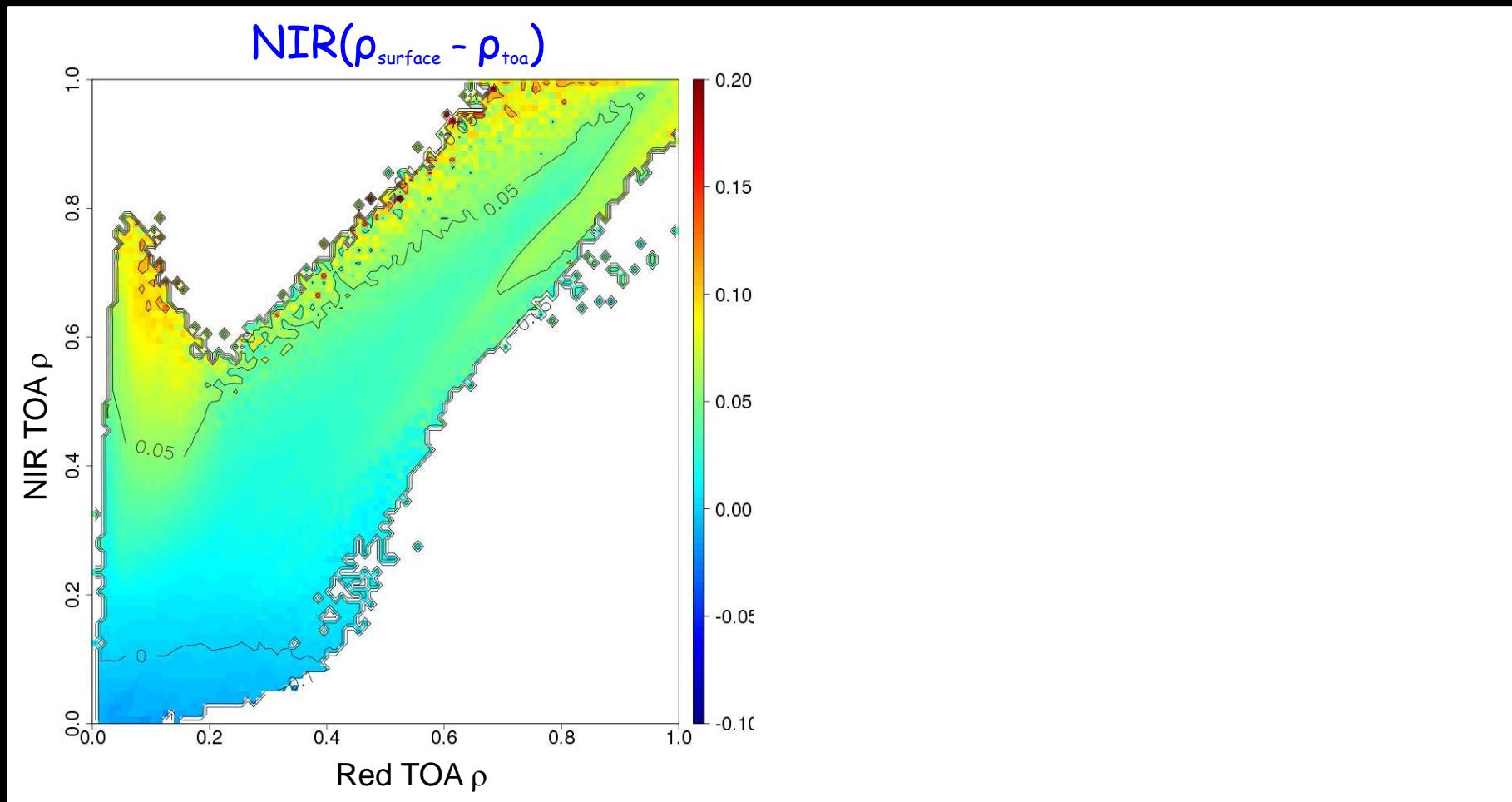
Version 3.0 compositing algorithm

V3.0 compositing algorithm informed by analysis of impact of atmosphere on WELD TOA reflectance

Pixels sampled every 40 pixels across CONUS from 12 monthly WELD composites, ignoring cloud and saturated WELD pixels, ~ 53 million 30m pixels



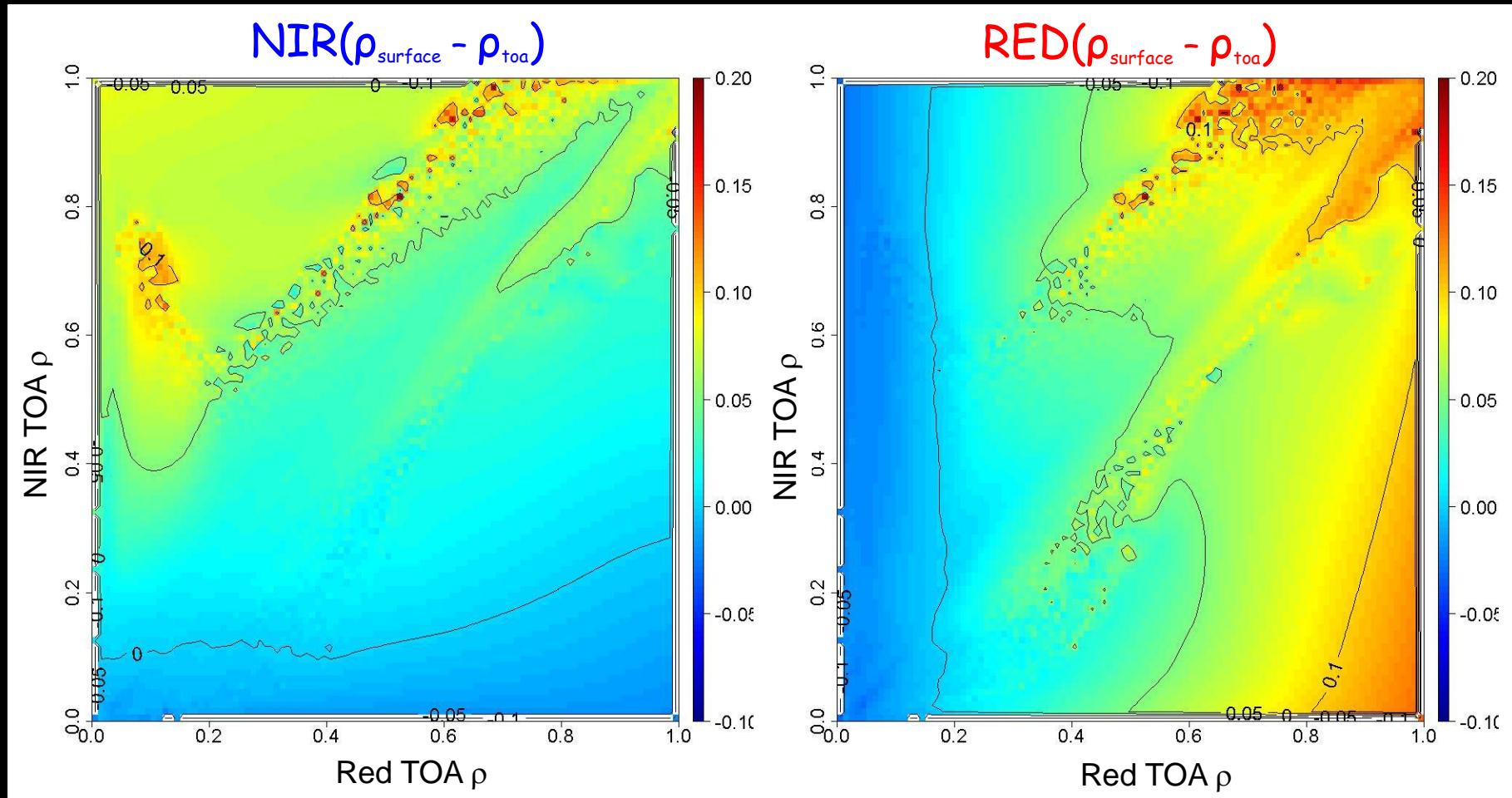
Spectral Lookup table of $\rho_{\text{surface}} - \rho_{\text{toa}}$ differences for red and NIR Landsat bands



generated from 90,542,838 30m CONUS pixel comparisons

Spectral Lookup table of $\rho_{\text{surface}} - \rho_{\text{toa}}$ differences for red and NIR Landsat bands

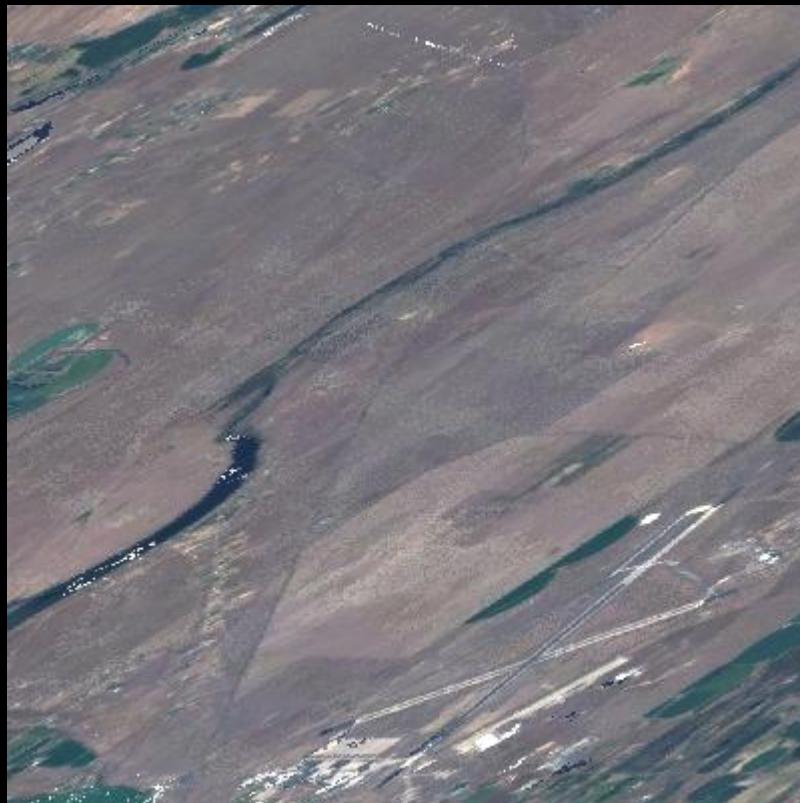
Natural neighbor interpolated to 0-1 reflectance range



generated from 90,542,838 30m CONUS pixel comparisons

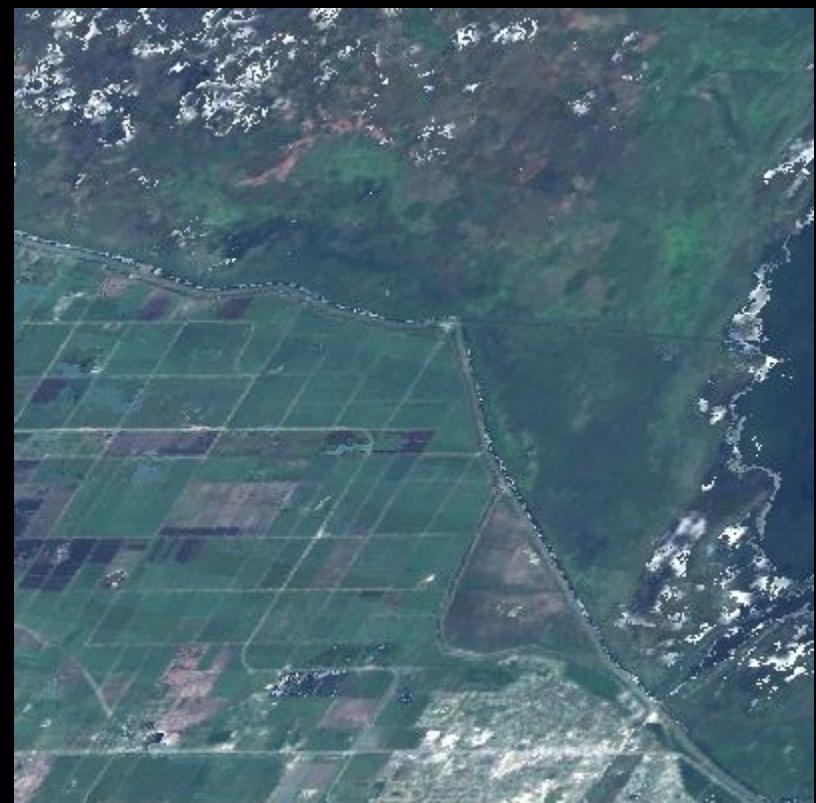
Global WELD June 2010 month composite TOA ρ version 2.2 algorithm

Columbia River Valley, Grant
Country International Airport



Generated from 3 Landsat 5 & 3 Landsat 7

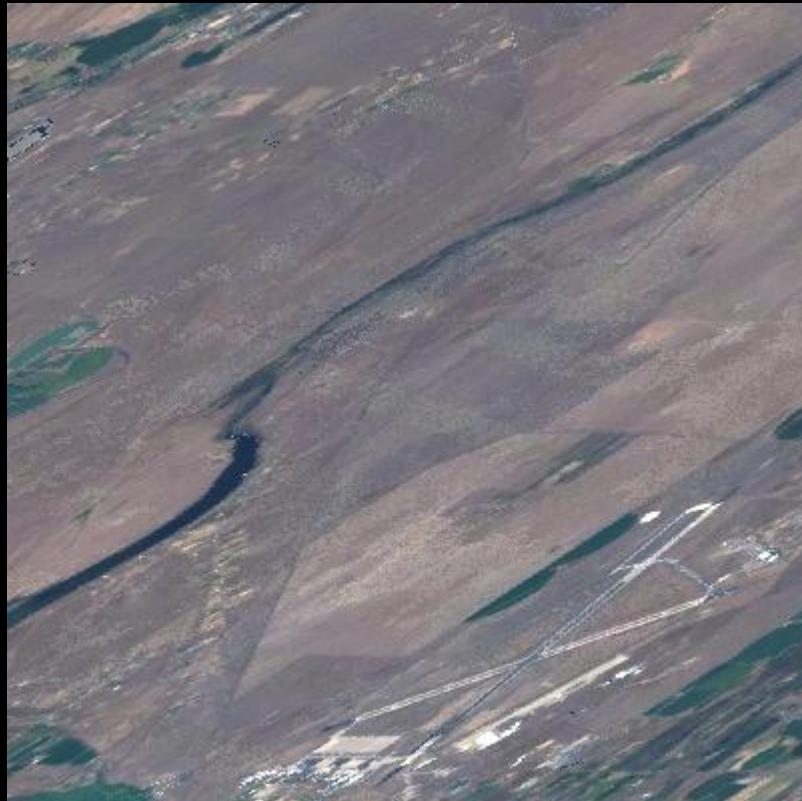
Central Florida Wetlands,
Lake Okeechobee



Generated from 1 Landsat 5 & 2 Landsat 7

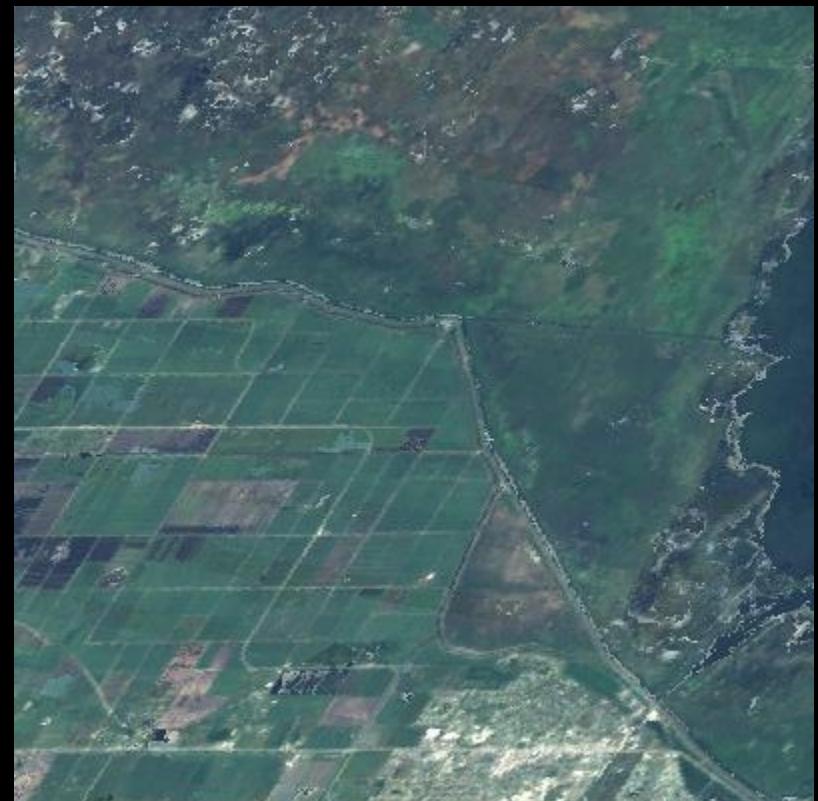
Global WELD June 2010 month composite TOA ρ version 3.0 algorithm

Columbia River Valley, Grant
Country International Airport



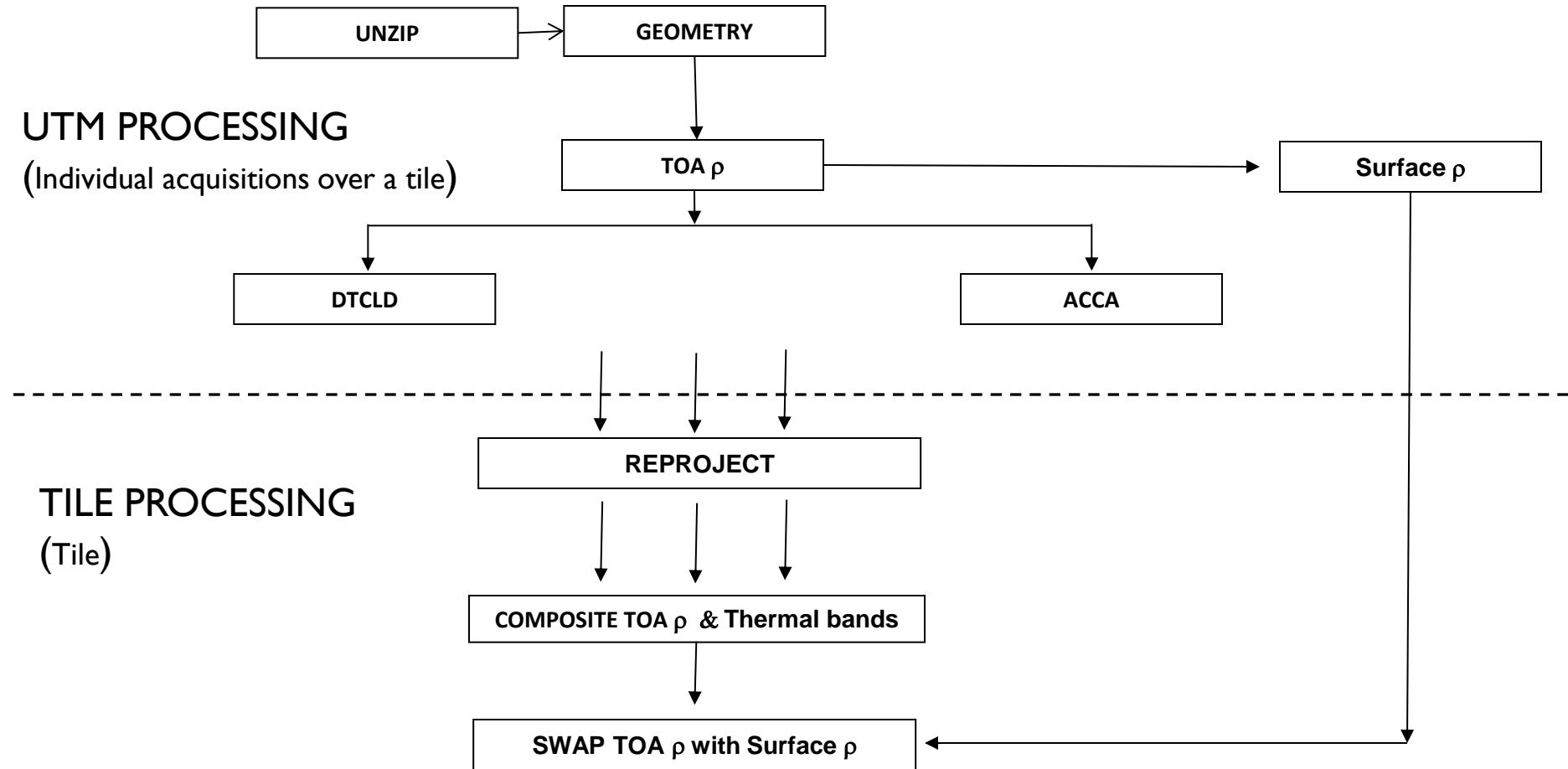
Generated from 3 Landsat 5 & 3 Landsat 7

Central Florida Wetlands,
Lake Okeechobee



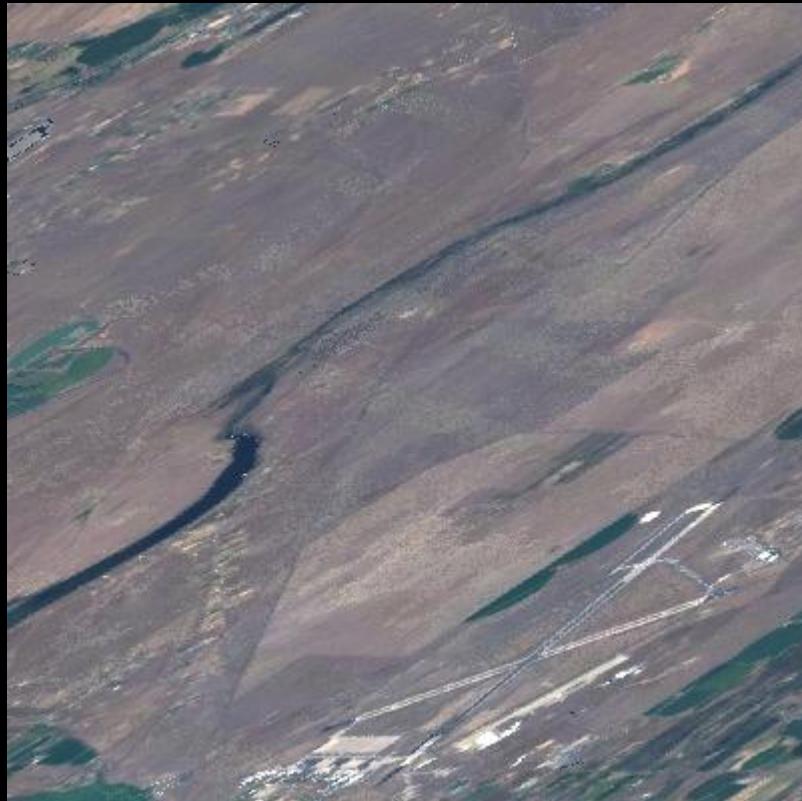
Generated from 1 Landsat 5 & 2 Landsat 7

Overview of Global Version 3.0 WELD Processing Sequence



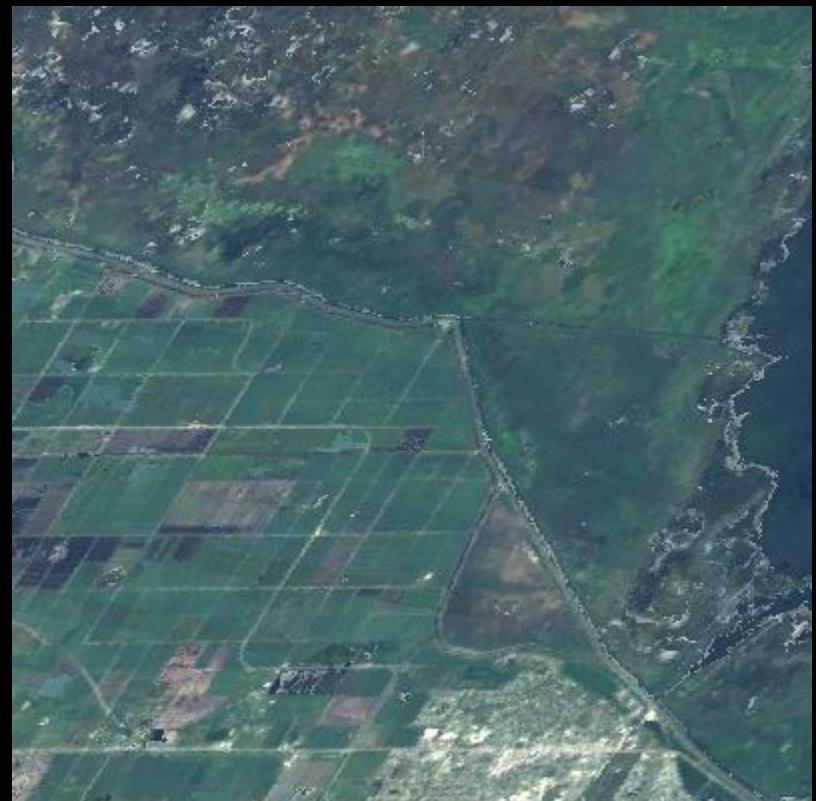
Global WELD June 2010 month composite TOA ρ version 3.0 algorithm

Columbia River Valley, Grant
Country International Airport



Generated from 3 Landsat 5 & 3 Landsat 7

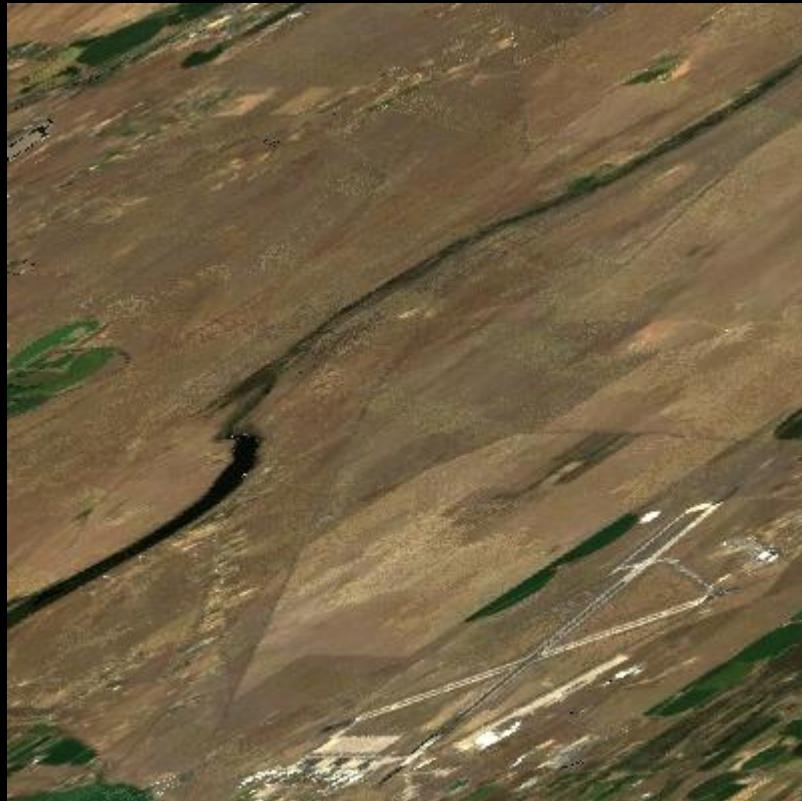
Central Florida Wetlands,
Lake Okeechobee



Generated from 1 Landsat 5 & 2 Landsat 7

Global WELD June 2010 month composite surface ρ version 3.0 algorithm

Columbia River Valley, Grant
Country International Airport



Generated from 3 Landsat 5 & 3 Landsat 7

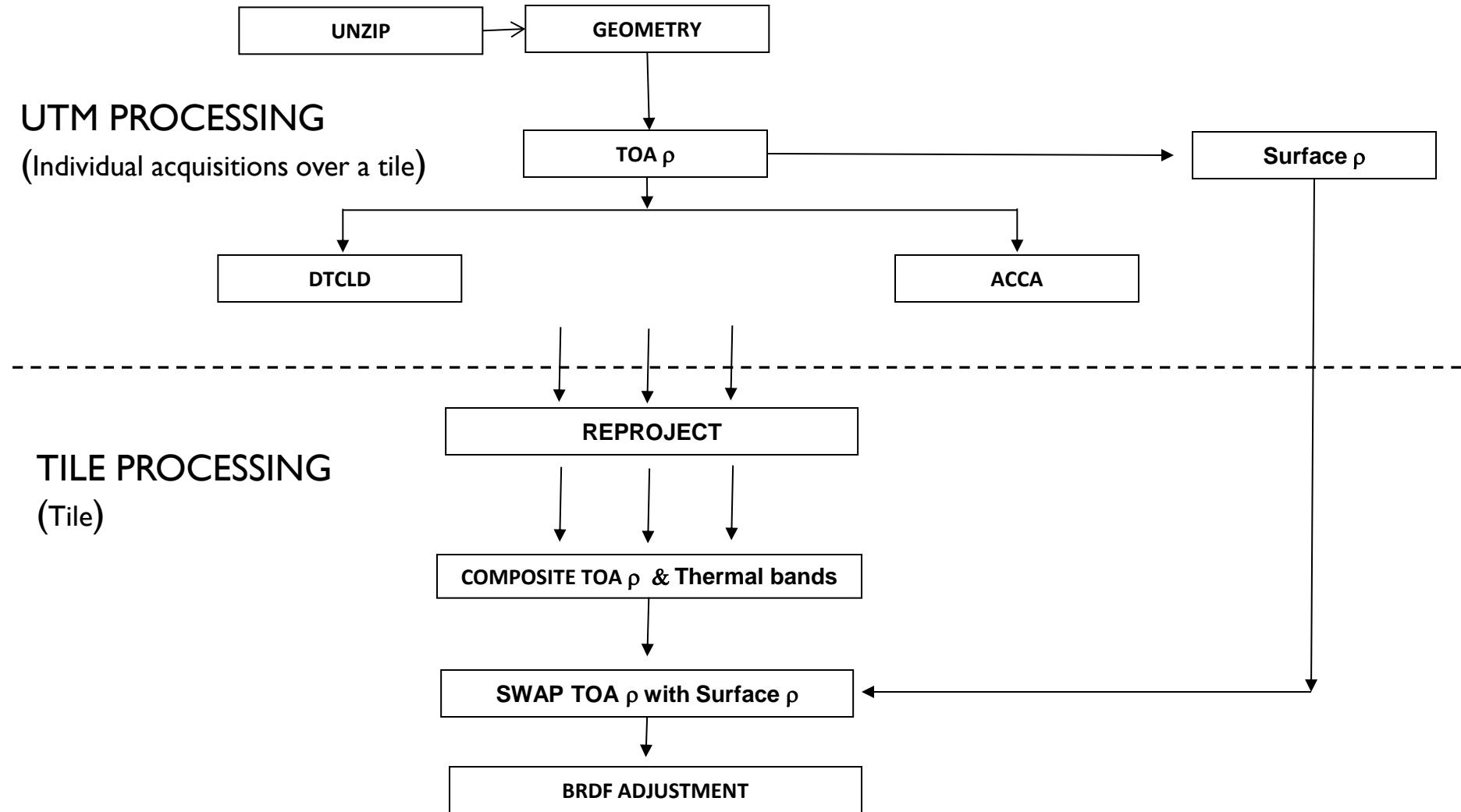
Central Florida Wetlands,
Lake Okeechobee



Generated from 1 Landsat 5 & 2 Landsat 7

LEDAPS atmospheric correction

Overview of Global Version 3.0 WELD Processing Sequence



Landsat MODIS-based BRDF Adjustment c-factor method

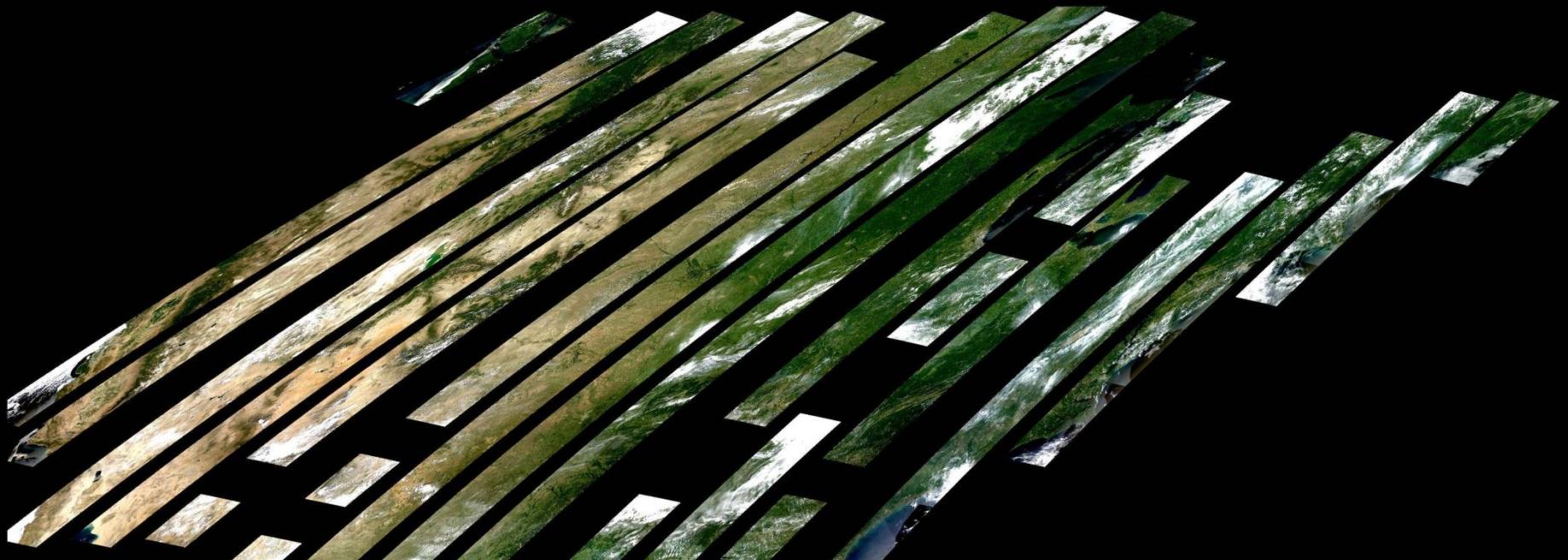
$$\hat{\rho}_{ETM+,t1}(\lambda_{ETM+}, \Omega_{nadir}, \Omega'_{solarnoon}) = c \times \rho_{ETM+,t1}(\lambda_{ETM+}, \Omega_{observed}, \Omega'_{observed})$$

$$c = \frac{\hat{\rho}_{MODIS,t1}(\lambda_{MODIS}, \Omega_{nadir}, \Omega'_{solarnoon})}{\hat{\rho}_{MODIS,t1}(\lambda_{MODIS}, \Omega_{observed}, \Omega'_{observed})}$$

$\hat{\rho}_{MODIS}$ computed from the MODIS 16-day 500m BRDF/Albedo product (MCD43) spectral BRDF model parameters

Roy, D.P., Ju, J., Lewis, P., Schaaf, C., Gao, F., Hansen, M., Lindquist, E., 2008. Multi-temporal MODIS-Landsat data fusion for relative radiometric normalization, gap filling, and prediction of Landsat data. *Remote Sensing of Environment* 112 (6), 3112-3130.

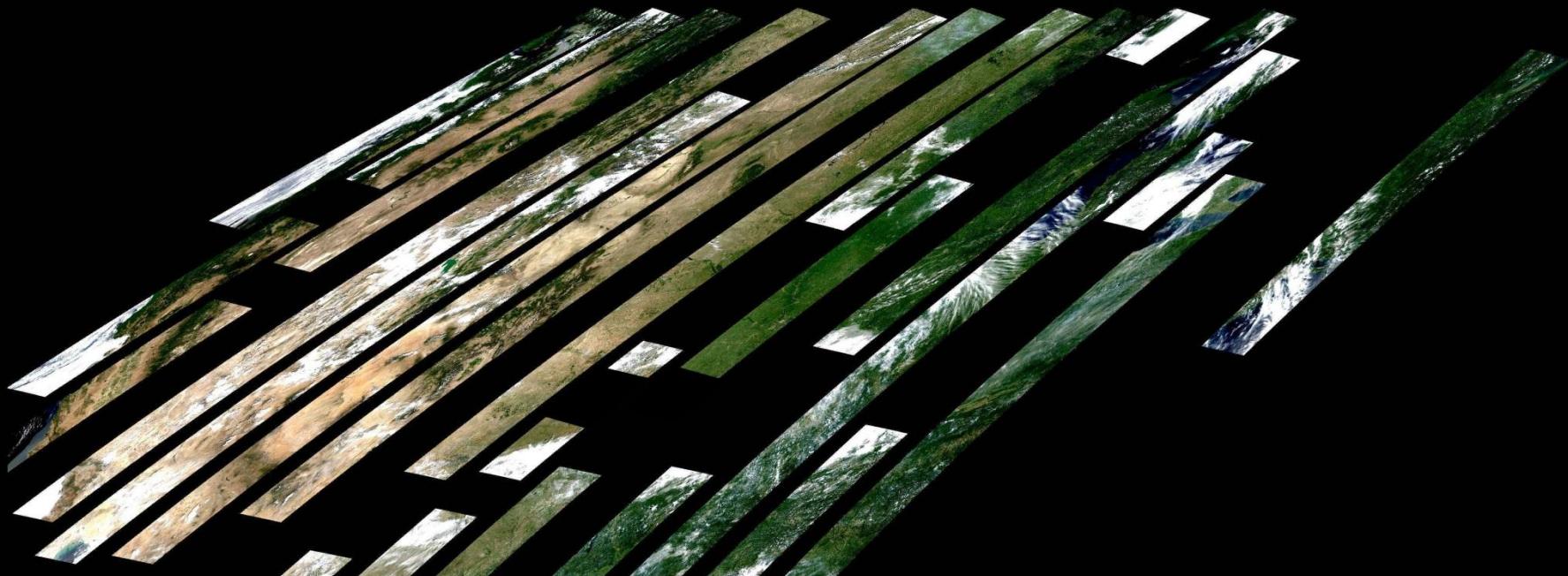
Conterminous United States (CONUS) Landsat 5 true color surface reflectance (week 27, 2010)



MODIS sinusoidal projection

Atmospherically corrected with LEDAPS code

Conterminous United States (CONUS) Landsat 7 true color surface reflectance (week 27, 2010)

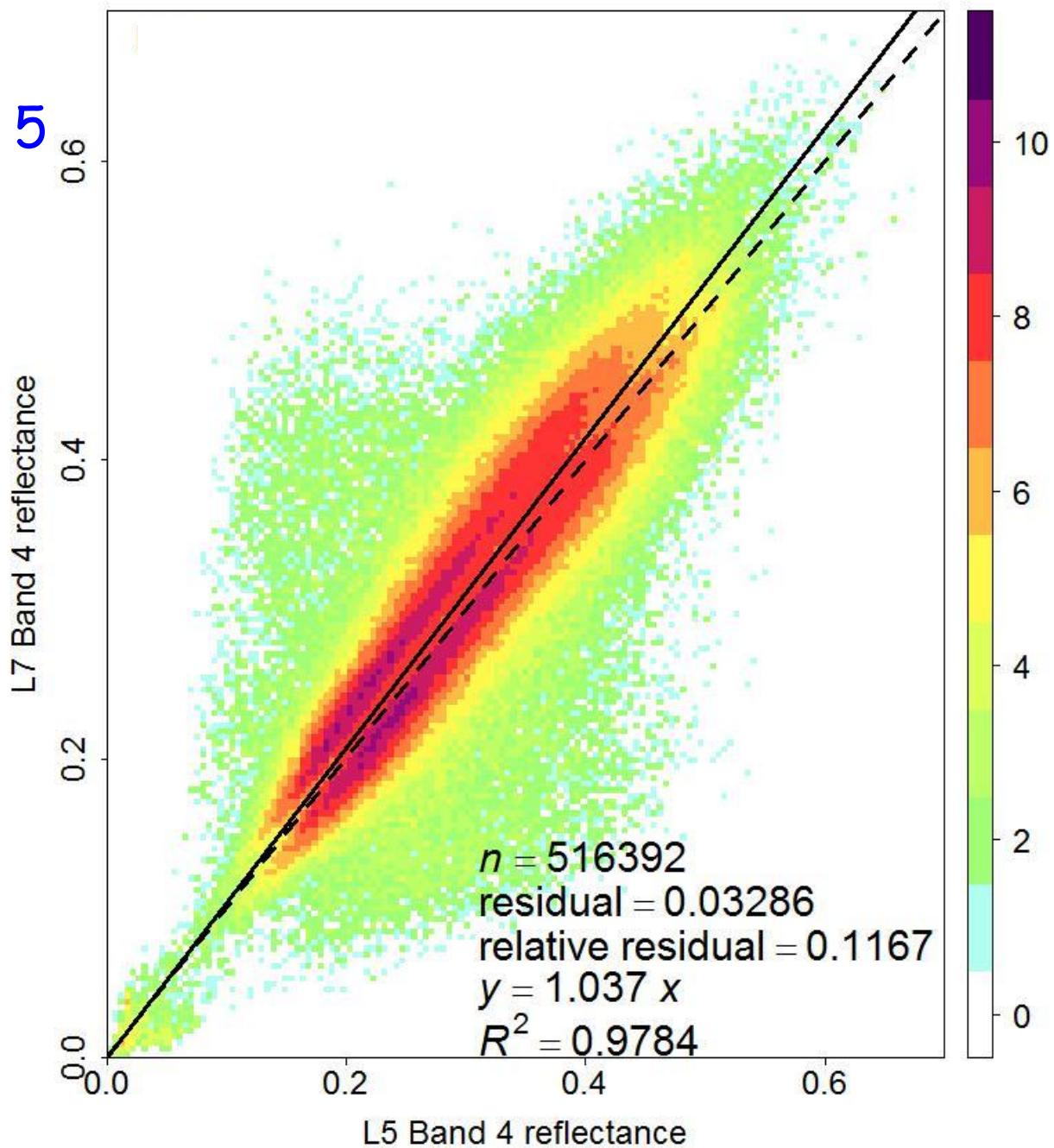


MODIS sinusoidal projection

Atmospherically corrected with LEDAPS code

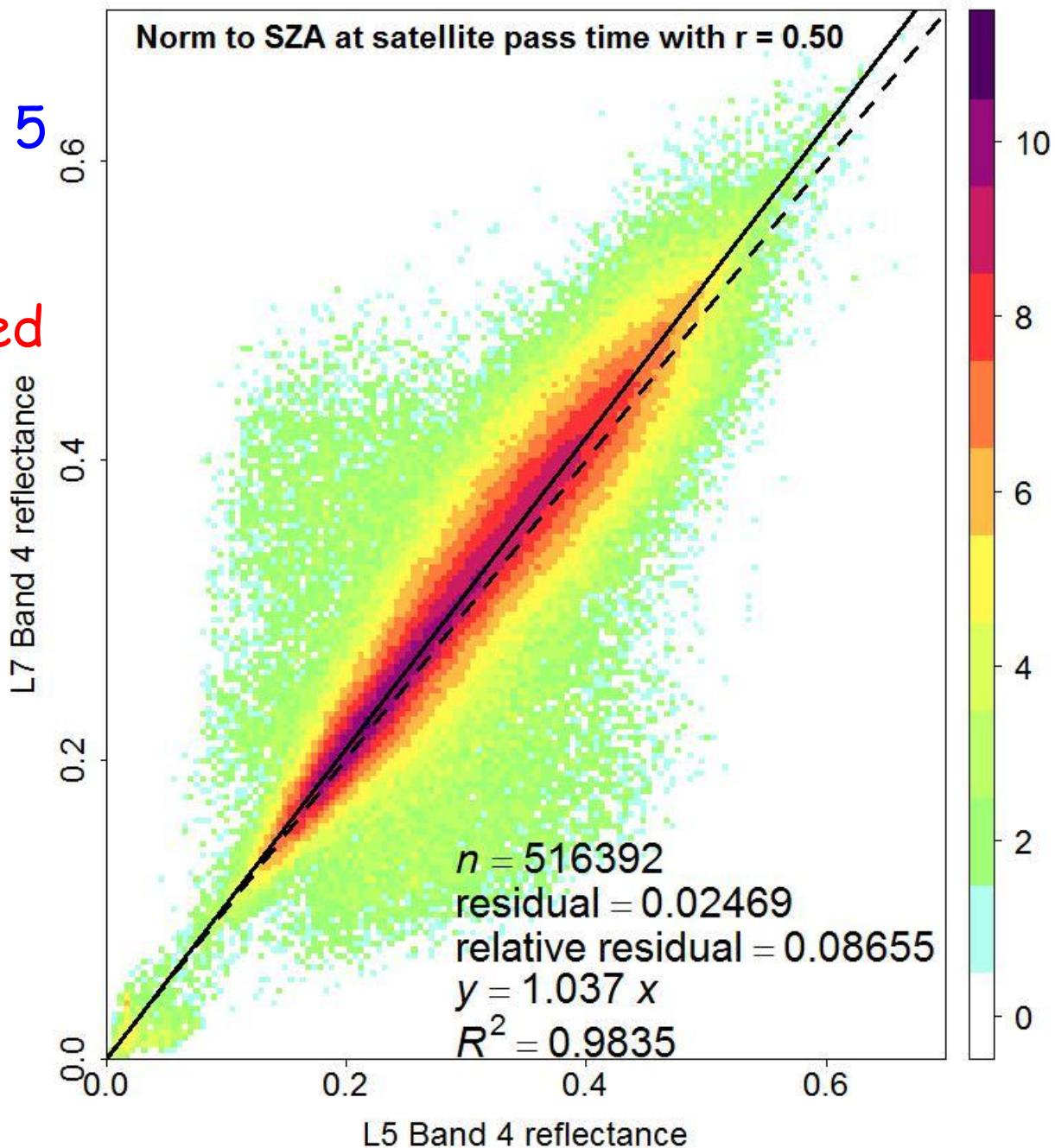
Scatterplot of Landsat 7 vs Landsat 5 NIR surface reflectance

516,392 overlapping
Landsat 5 & 7 pixels
(found by considering
every 40th WELD tile
non-cloudy pixel
across the CONUS)



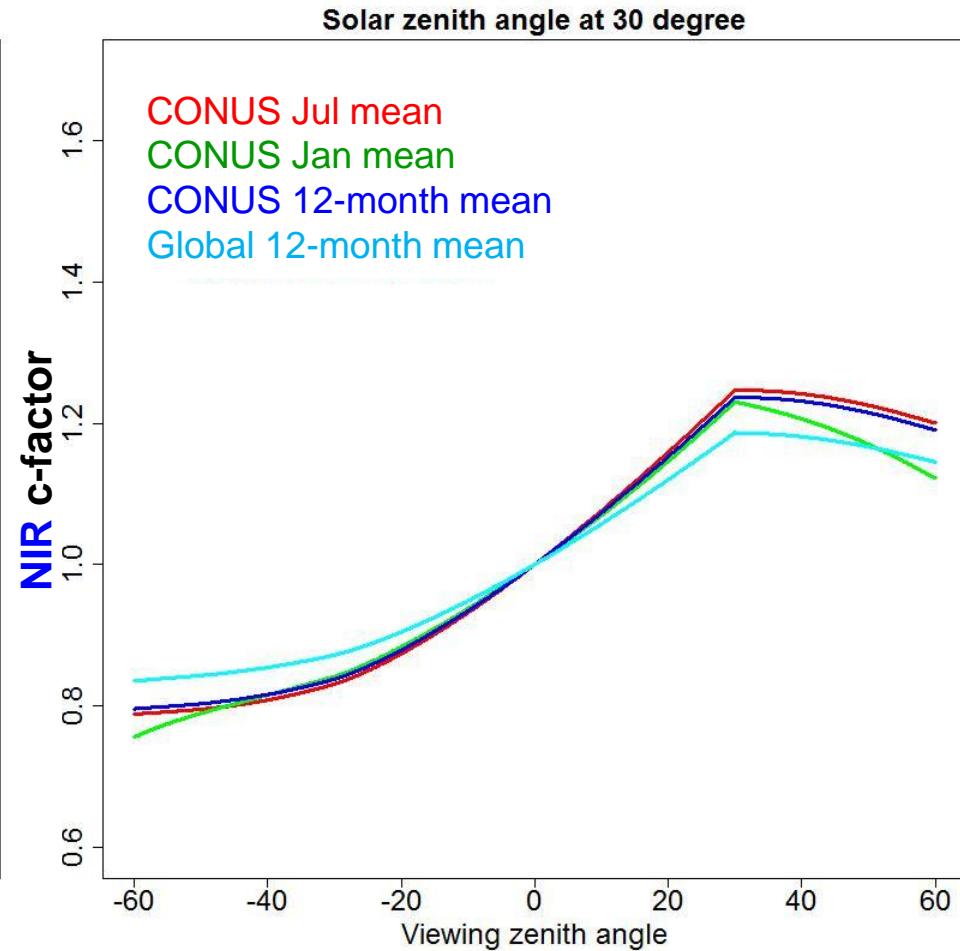
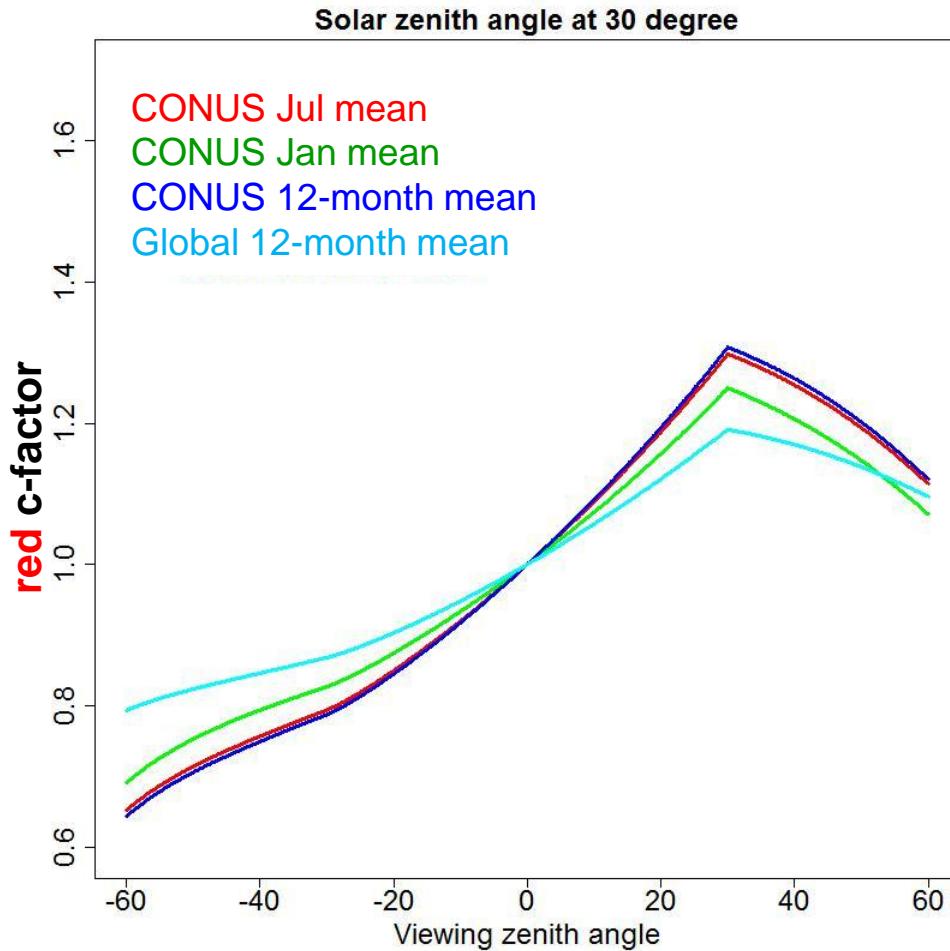
Scatterplot of
Landsat 7 vs Landsat 5
MODIS MCD43
BRDF parameter
climatology normalized
to nadir &
satellite overpass
solar zenith
NIR surface
reflectance

516,392 overlapping
Landsat 5 & 7 pixels
(found by considering
every 40th WELD tile
non-cloudy pixel
across the CONUS)



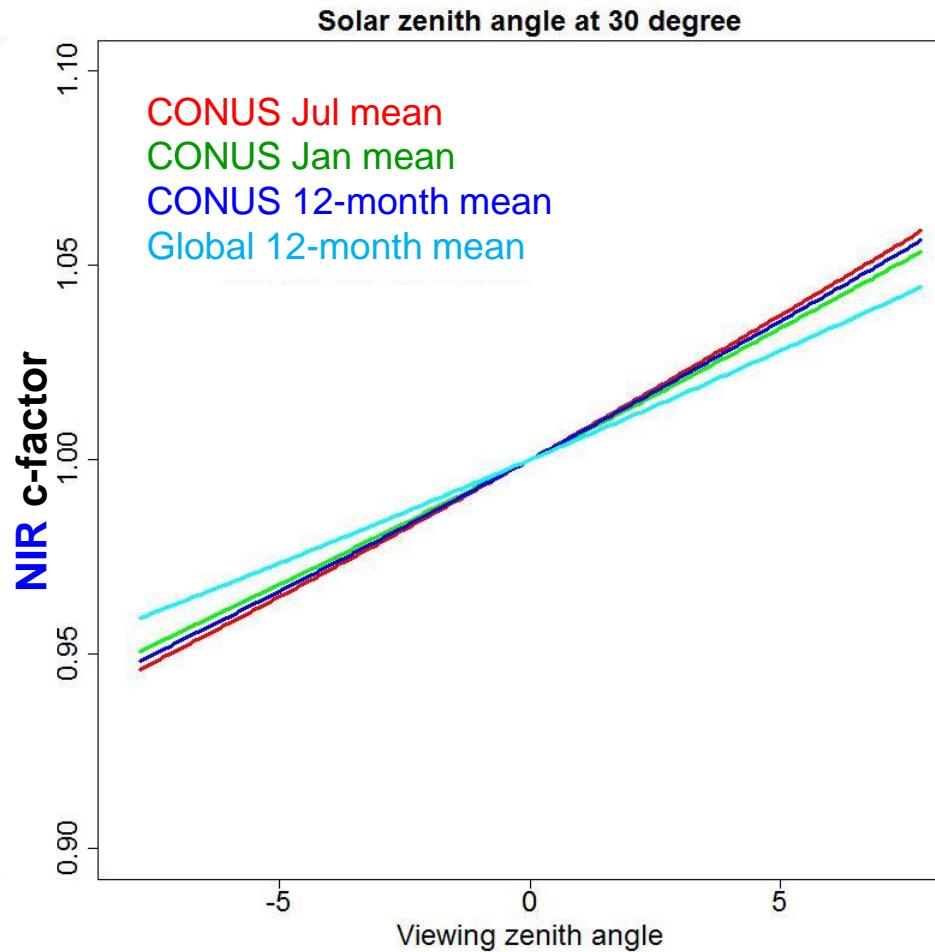
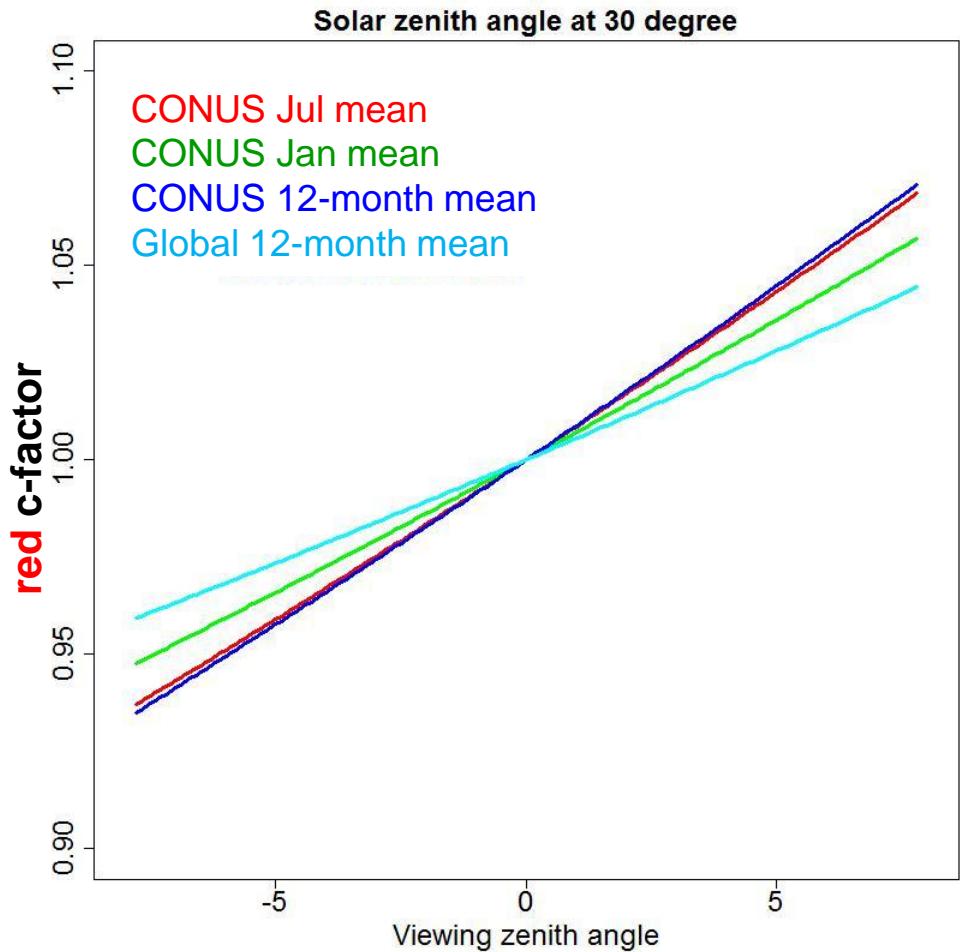
c-factors over MODIS 110° FOV using just 3 mean MDC43 model parameters

$$\rho(\lambda, \Omega, \Omega') = f_{iso}(\lambda) + f_{vol}(\lambda)k_{vol}(\Omega, \Omega') + f_{geo}(\lambda)k_{geo}(\Omega, \Omega')$$



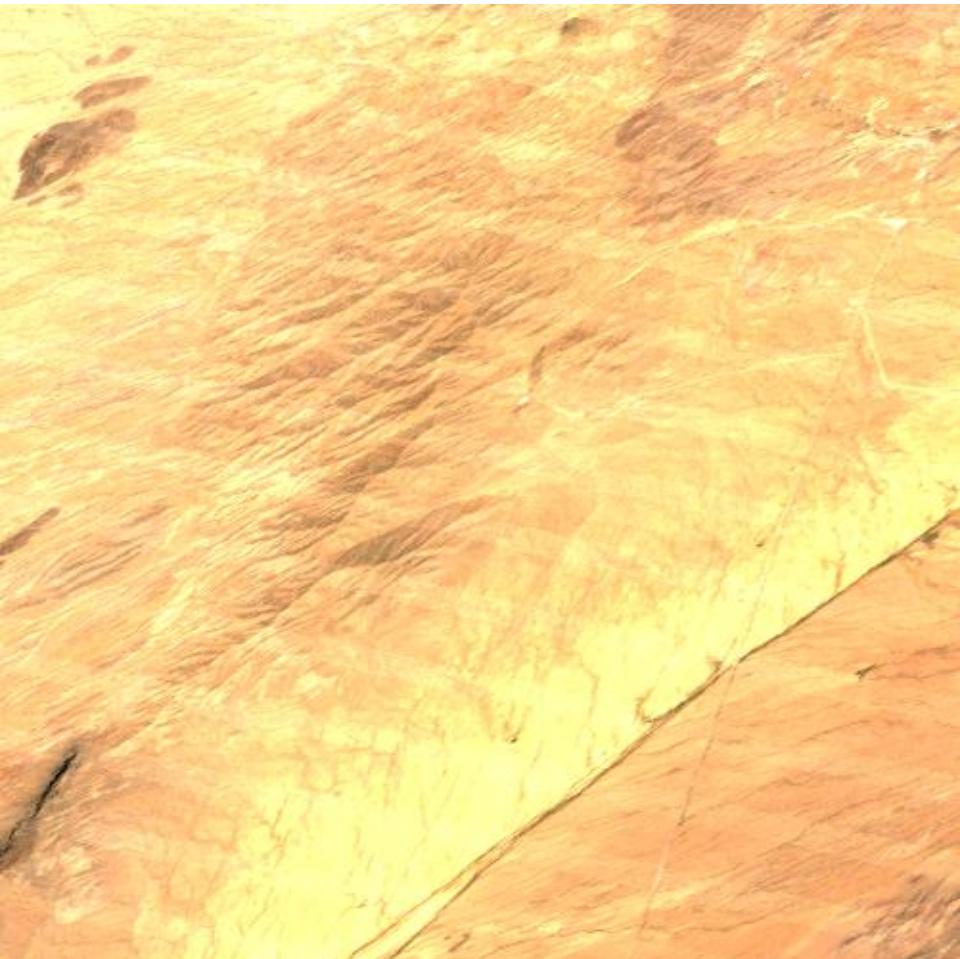
c-factors over Landsat 15° FOV using just 3 mean MDC43 model parameters

(similarly linear over Sentinel-2 20.6° FOV)



WELD Landsat 5 & 7 surface reflectance

Version 3.0 one week composite



Arizona
500 x 500 30m pixels

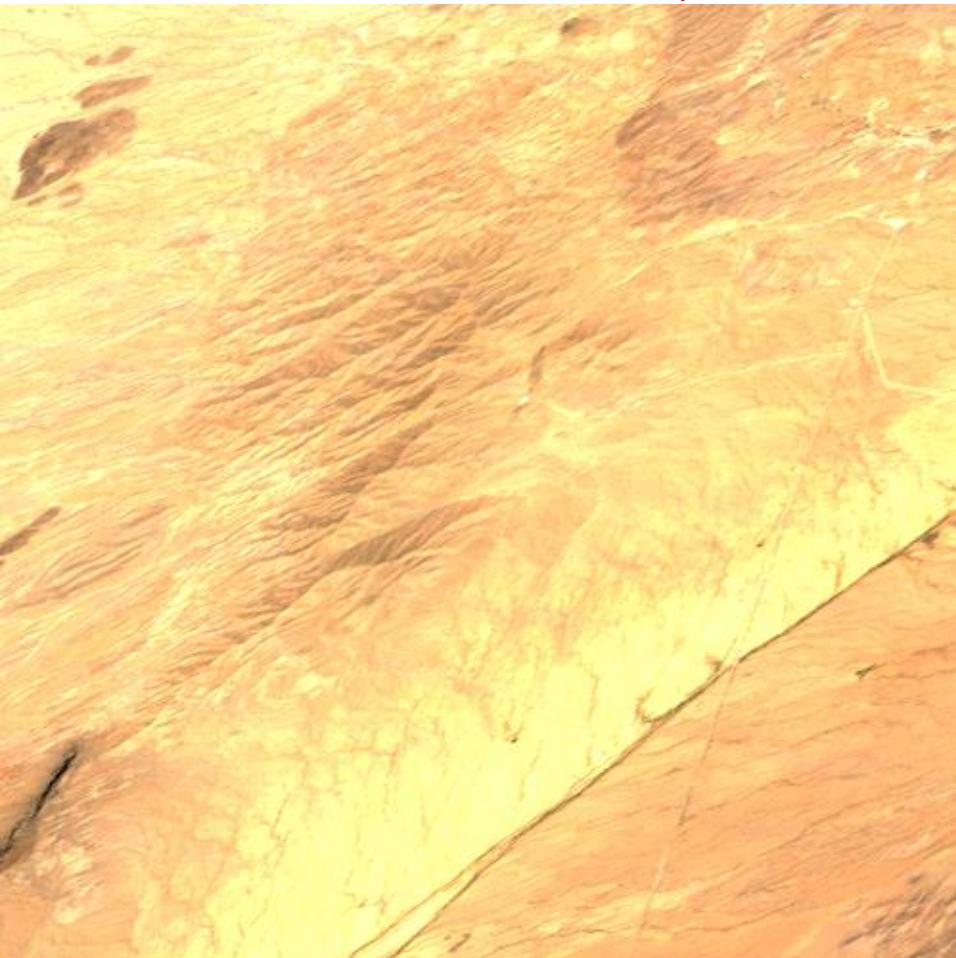


Mississippi

WELD Landsat 5 & 7 surface reflectance

Version 3.0 one week composite

NBAR (global 12-month 3 mean MDC43 model parameters)
nadir view zenith, satellite overpass time solar zenith



Arizona

500 x 500 30m pixels



Mississippi

TOA Reflectance
Global WELD V.3.0 NEX Processing July 2010

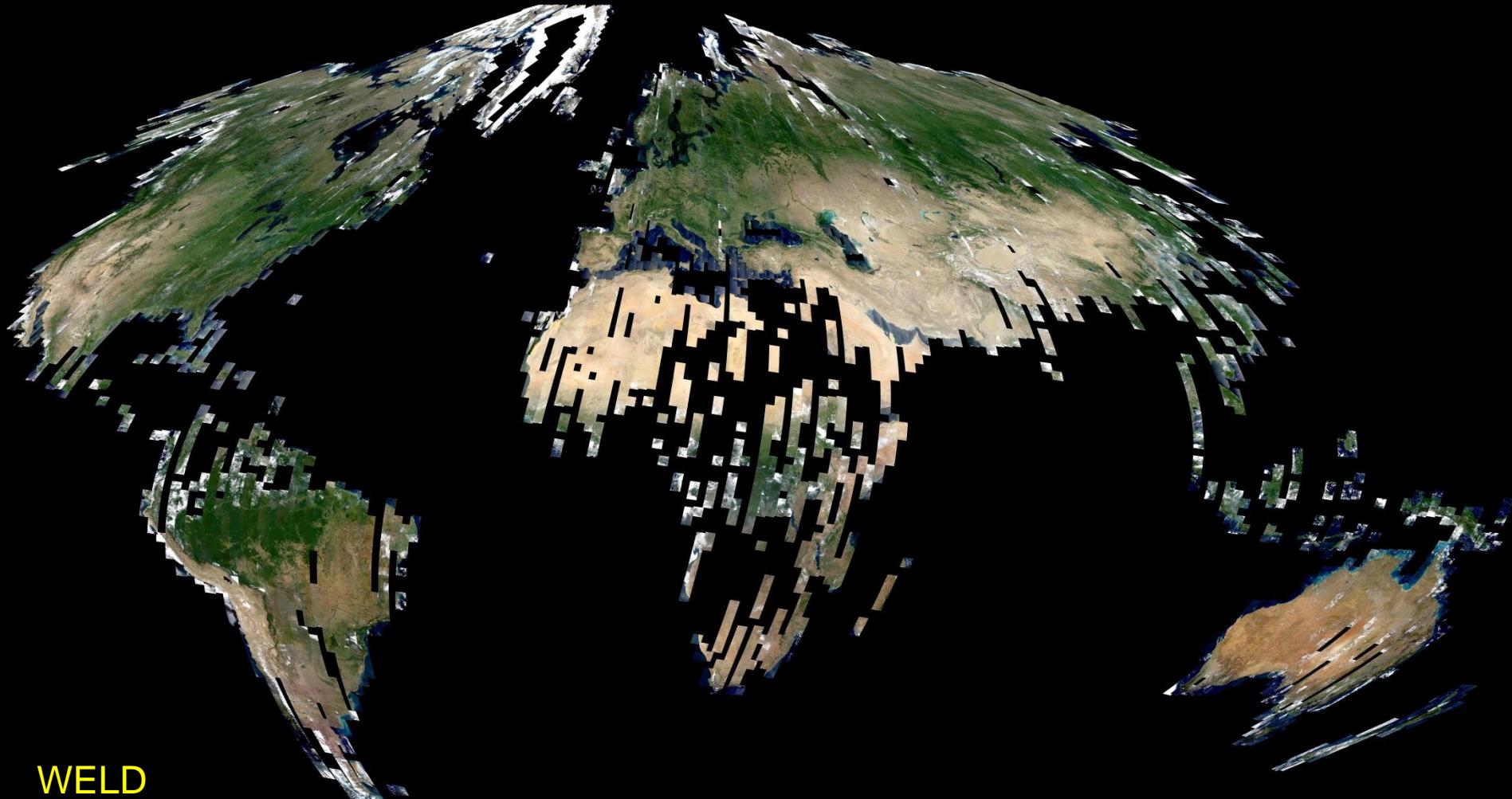
12,621 L1T scenes (5069 Landsat 5 & 7,552 Landsat 7)



MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

Surface NBAR Global WELD V.3.0 NEX Processing July 2010

12,621 L1T scenes (5069 Landsat 5 & 7,552 Landsat 7)



WELD

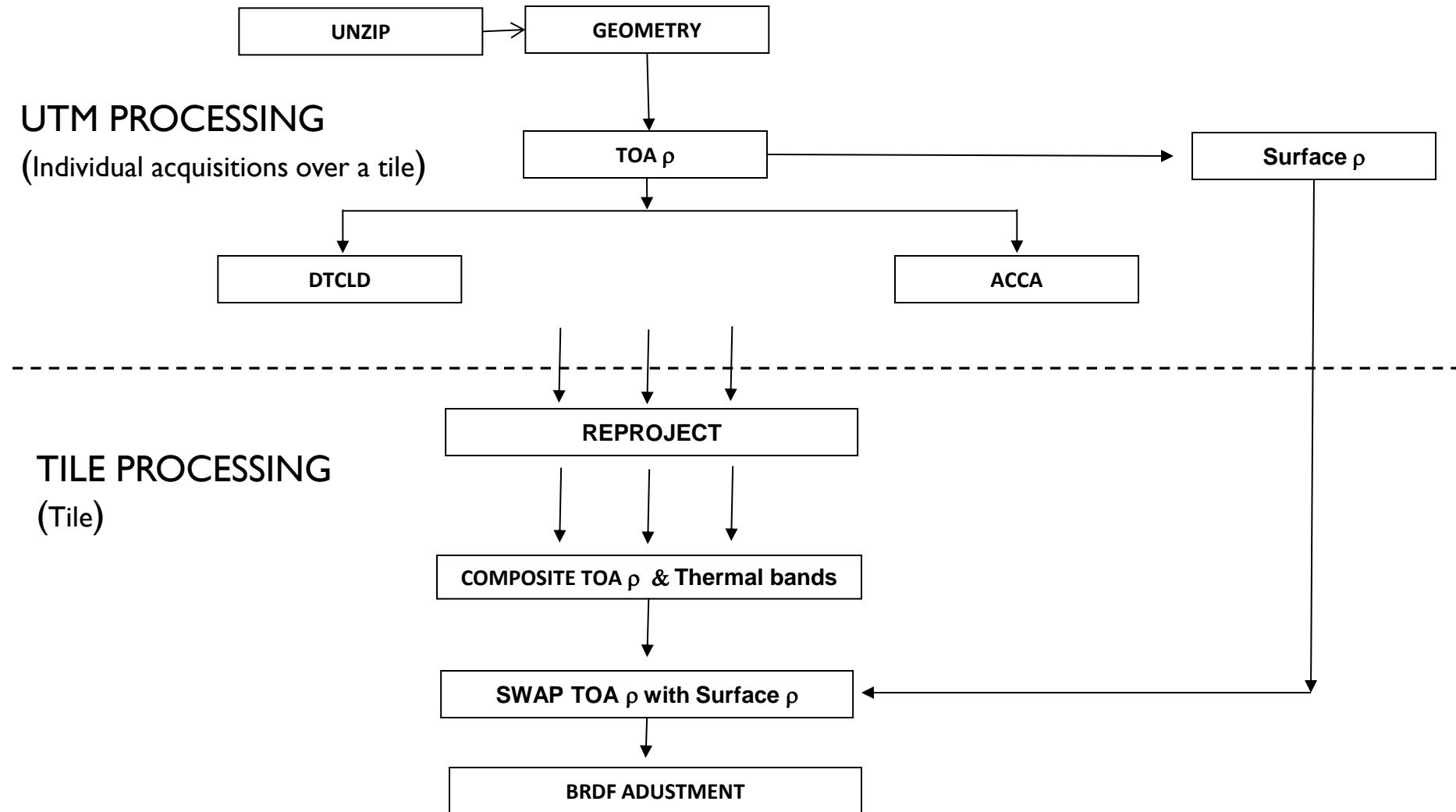
Version 3.0 will be available from EROS portals
early Fall

MODIS sinusoidal projection
29,652 x 14,826 1.35km browse pixels

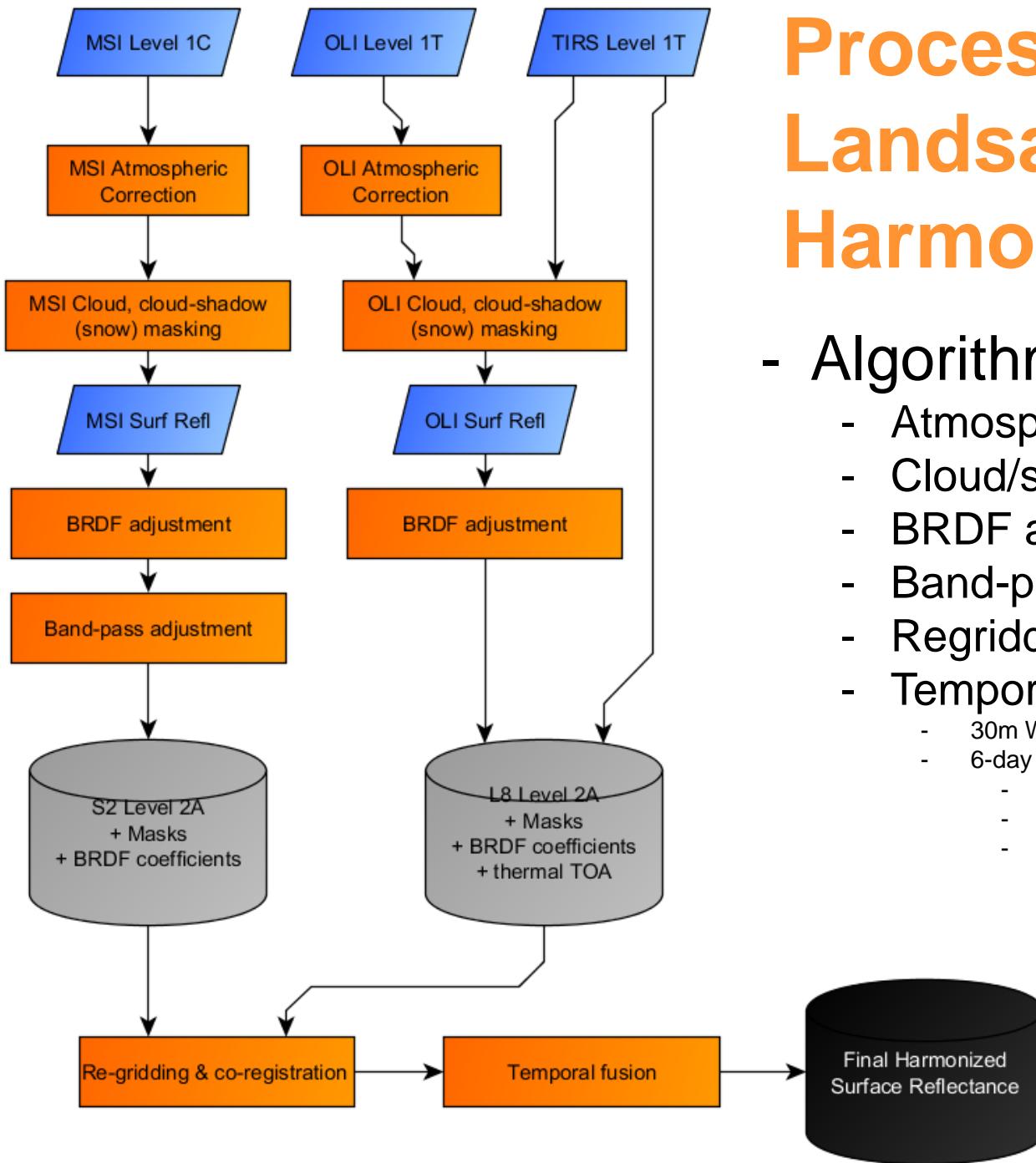
Global Version 3.0 WELD processing sequence

Will work to generate

- similar but separate L8 and S2 gridded products
- combined L8-S2 gridded products (more research needed ...)



Processing for Landsat/S2 Harmonization



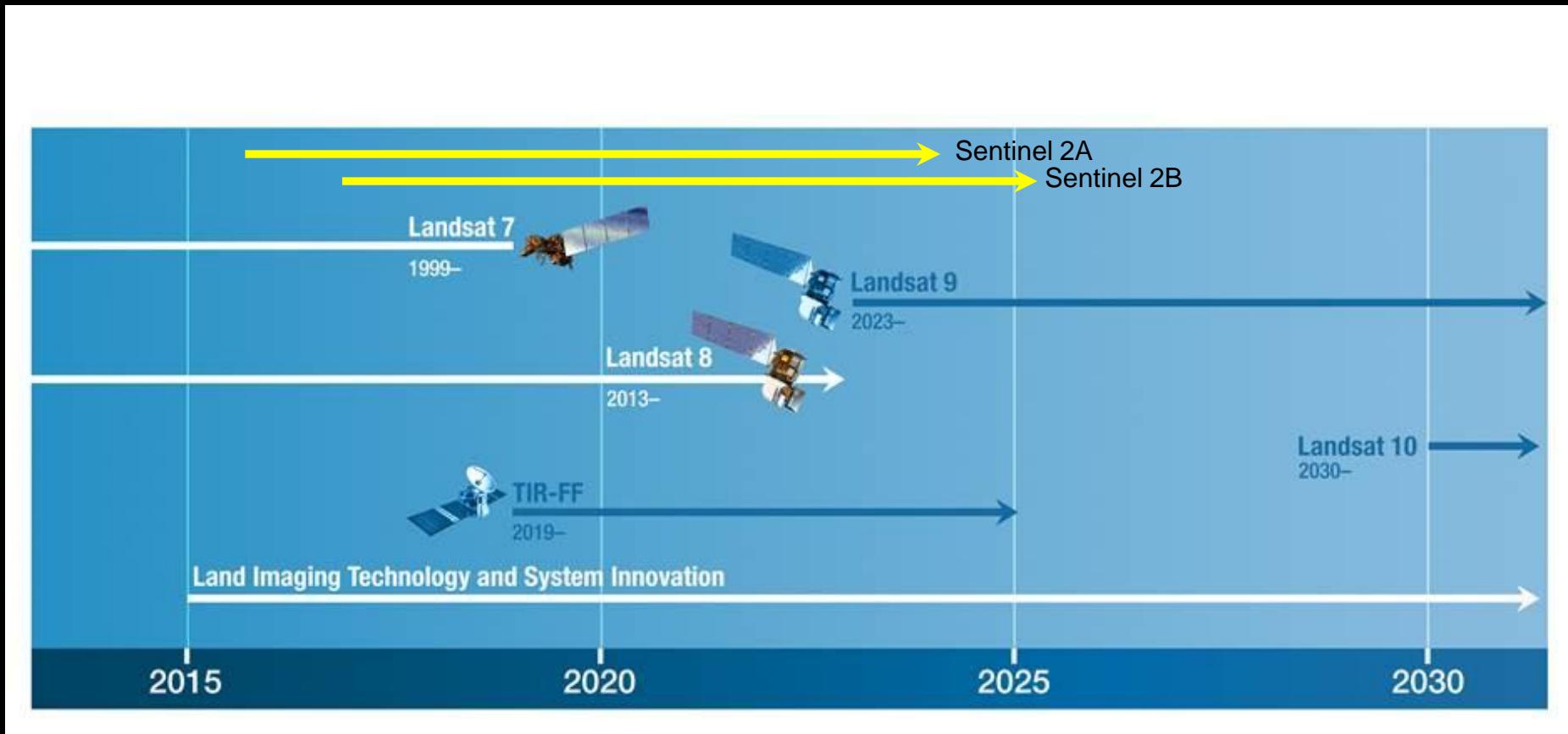
- Algorithms

- Atmospheric correction
- Cloud/shadow masking
- BRDF adjustment to nadir view
- Band-pass adjustment to OLI
- Regridding
- Temporal Compositing
 - 30m WELD sinusoidal gridding
 - 6-day composites
 - TIR from best Landsat-8
 - Red-edge from best S2a
 - VSWIR from either



(Jeff Masek, yesterday)

NASA USGS commitment for Landsat 9 & 10 !



ESA commitment for Sentinel 2A & 2B !